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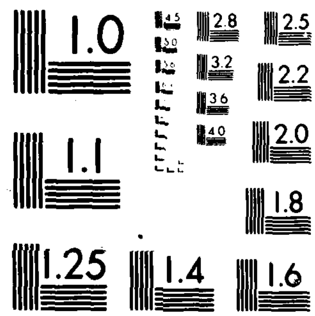

MICROCOPY RESOLUTION TEST CHART
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T. [illegible]
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This report presents the results of a study of the nonoperating failure rates of USAF avionic equipments. Quantitative assessment data on 26 different equipment/aircraft applications are included. The nonoperating failure rates as determined by three different methods utilizing Air Force maintenance data were measurably significant. On average, MTBF assessment results are improved by 22% when nonoperating failures are excluded from operational MTBF assessments. Average operating to (Cont'd) over

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nonoperating failure rate ratios for the equipments investigated ranged from 41 to 188. Comparisons between several reliability prediction methods and operational reliability levels achieved are included. Based on the six equipment types analyzed, it is concluded that field nonoperating failure rates cannot be predicted to a reasonable degree of accuracy by using any of the established prediction methods.

PREFACE

This Final Technical Report on the Nonoperating Failure Rates for Avionics Study was prepared by the Design Effectiveness Operations organization of the Hughes Aircraft Company, Culver City, California, under Contract F30602-77-C-0187, for Rome Air Development Center, Griffiss Air Force Base, New York. The major objectives of the study were to investigate the existence and magnitude of nonoperating failure rates for avionic equipments.

The contract was issued on 19 September 1977 by Rome Air Development Center, Griffiss Air Force Base, New York. Mr. Eugene Fiorentino (RBRT) was the RADC Project Engineer. The period of performance was from 1 September 1977 through 1 March 1979.

Technical consultation and assistance in the acquisition of the required MDC system maintenance data were provided by Mr. Chuck Gross (HQ AFLC/LOEP), and Mr. William Harrison (HQ AFLC/ACVM), whose efforts contributed significantly to the successful completion of this study. Mr. George A. Kern was the Hughes study program manager. Mr. Kern and Messrs. Irving Quart, Steve S. Tung, and Kam L. Wong were the principal investigators. Appreciation is also extended to Dr. J. Kallis for his assistance in helping organize and summarize the results for publication in this final report. Other Hughes study team members were: R. Gibson, E. Gulian, G. Heckman, H. Jaffe, V. Jones, R. Knopf, R. Lorenz, L. McWilliams, Dr. S. Moite, J. Rose, and W. Zeller.

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EVALUATION

The objective of this study was to assess the relative significance and magnitude of nonoperating environmental effects on avionic equipment reliability in relation to predicted and field observed failure rates.

The objectives have been satisfactorily achieved. Results of the investigation indicate that nonoperating effects contribute approximately 10-30% to total observed failures and that such effects can significantly impact operationally ready rates. The study has highlighted the need for including the effects of the nonoperating environment in reliability modeling techniques. In addition, the study has shown that field MTBF assessments which fail to properly account for time of failure occurrence, can lead to seriously misleading estimates of mission reliability.

Study results will be used in the further development of avionics reliability prediction techniques which more accurately reflect field operating and nonoperating conditions. The study has also contributed valuable findings pertaining to the use of field performance data in future reliability studies.

Eugene Fiorentino

EUGENE FIORENTINO
PROJECT ENGINEER

MANAGEMENT SUMMARY

The lack of correlation between predicted, demonstrated, and field reliability of avionic equipment has been a matter of concern to the Air Force for some time. Recent studies indicate predicted MTBF to be between 5 and 50 times greater than field MTBF. When comparing the demonstrated to field MTBFs, the corresponding ratios are between 3 to 1 and 20 to 1. Furthermore, predicted reliability is consistently higher than actual field operational reliability.

A previous study performed by Hughes Aircraft Company for RADC entitled Operational Influences on Reliability (OIR) identified the causes of this lack of correlation. The need for a better understanding of the characteristics and magnitude of avionic equipment failures accrued during nonoperating time was identified during the OIR study. The reason for interest in this parameter was that the method used by AFLC for assessing equipment MTBF is based on the count of all failures (regardless of when discovered) divided into equipment operating time. Since some fraction of these failures may have occurred during nonoperating time, the resultant value of assessed MTBF tends to be lower than the value of operating MTBF that would be obtained by including only those failures that occurred during the operating time of interest for the assessment. Although the nonoperating failure rates may be only a small fraction of the operating failure rates, e.g., 1/20th, the relative amount of time accrued in the nonoperating state is about 20 times greater than the operating time. Therefore, the assessed MTBF in the field could easily be doubled if only operating failures and operating time were included in the assessment of field MTBF. One of the key recommendations of the OIR study was to establish nonoperating failure rates for various types of avionic equipments. This recommendation led to the present study.

The primary objectives of the Nonoperating Failure Rates for Avionics (NOFRA) study were

1. Investigate the existence and magnitude of nonoperating failure rates for avionics.
2. Establish the significant influencing factors by which nonoperating failure rates are affected.
3. Recommend methods for incorporating study findings into MIL-HDBK-217B.

More specific objectives of the study included: (1) Predict operating MTBFs for a representative mix of avionic equipments using the methods of MIL-HDBK-217B, and compare the predictions with the results of field assessed MTBFs based on present measures of field reliability (using total failures) and/or field reliability considering only operating failures, (2) Determine the extent to which nonoperating failures affect the measured MTBF, and (3) Ascertain how parts mix affects nonoperating failure rates.

The major elements of the analytical tasks are shown in Figure MS-1 in the form of a study flow diagram. The data flow began with the acquisition of the AFLC field data pertaining to each of the equipments and weapon systems included in the study. These data and data retrieved from Hughes data files on the equipment and weapon platform characteristics were then organized, validated, and reduced to develop the data baseline. An added input to this data baseline was the predicted MTBF values resulting from the new baseline predictions for the six equipment types included in the study based on MIL-HDBK-217B. A literature search provided the latest information on models and factors affecting failure rates, especially the environments to which avionic equipments are exposed and their effects, and the effects of equipment age and mission duration on failure rates. The following approaches were used to quantify the nonoperating failure rate characteristics of the equipments included in the study: (1) Direct quantification based on maintenance data analysis (measured field failure rates based on the when discovered codes), and (2) Indirect quantification using regression analysis

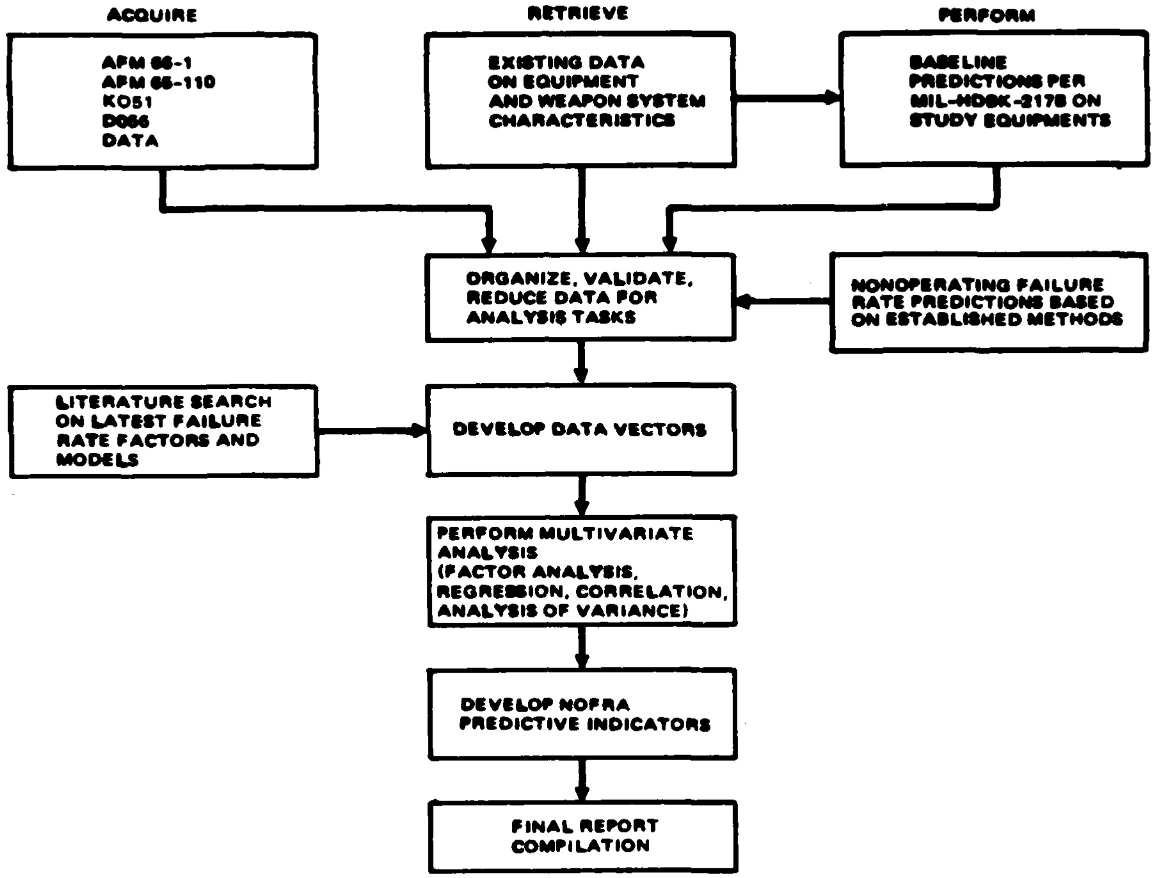

Figure MS-1. Flow diagram for NOFRA study.

methods in which mission duration, duty cycle, and parts mix were used as the variables of interest. Data vectors in terms of matrices were developed based on the available data and the requirements from the models. Statistical analyses were then performed leading to the development of non-operating failure rate indicators. All the data and the findings were then compiled into this final report.

The data base used for this study was a compromise between the study requirements and the limitations of available resources (person-hours) for performing the new predictions, and compiling and reducing the field operational data. The final selection of avionic equipment applications (combinations of an equipment and a weapon platform) is listed in Table MS-1. They

TABLE MS-1. EQUIPMENT/WEAPON PLATFORM MATRIX

Equipment	Weapon Platform Types																
	Fighters/Interceptors											Bombers, Transports					
	A-7D	A-10	F-15	F-100	F-101	F-111A	F-111D	F-111E	T-37	T-38	T-39	B-52D	B-52G	B-52H	C-130	KC-135	C-141
1. ARN-118 TACAN	X	X				X	X	X		X	X	X	X	X	X	X	X
2. ARC-164 UHF Radio	X	X		X	X				X	X	X	X	X	X	X	X	X
3. AAQ-6 FLIR													X	X			
4. C-1108 Video Monitor													X	X			
5. AYK-12 Computer			X														
6. ARN-131 OMEGA Nav.															X		

were drawn from five USAF operating commands (ADC, ATC, MAC, SAC and TAC) and comprise a one-year data base consisting of six AN-designated equipment types which collectively represent 3,817,000 equipment flight hours (CY 1978), 9,255 equipments, 17,500 maintenance action record sets, and 10,600 failures.

The major results of the study are as follows. The calculated MTBF (using only failures detected during operating periods) was an average 23 percent higher for the six equipment types investigated than the AF reported MTBF (which included all failures). The MTBF difference was more than 50 percent for the C1108 video monitor. The percentage MTBF improvement factors derived for each of the equipment types studied are presented in Figure MS-2. Comparable values were obtained using two other indirect methods for the ARN-118 TACAN and the ARC-164 UHF radio, as shown in Table MS-2. Comparing the operating to nonoperating failure rate ratios indicates that this characteristic varies over a wide range as shown in Figure MS-3. The average ratios of measured operating to nonoperating failure rates for the six equipment types investigated ranged between 41 and 188 and had an average value of 113. This method, however, possibly overestimates the ratio, because

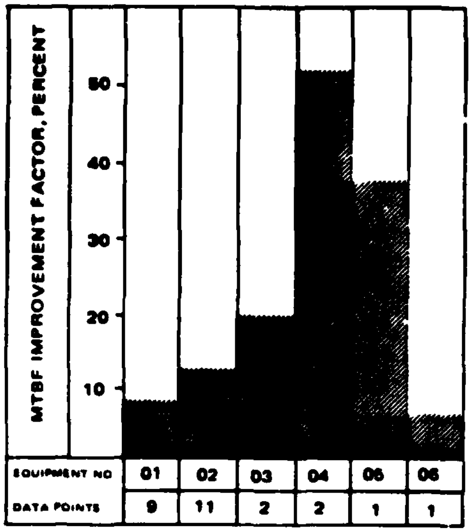

Figure MS-2. MTBF improvement factor.

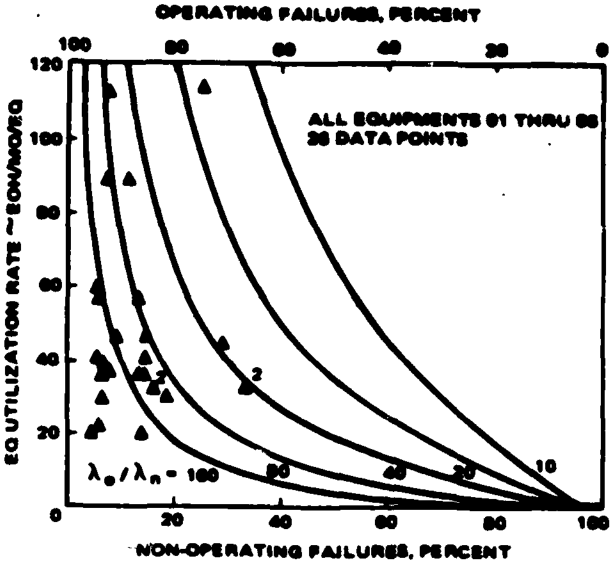

Figure MS-3. Ratio of operating to nonoperating failures.

TABLE MS-2. MTBF IMPROVEMENT OVER AIR FORCE REPORTED MTBF

Analysis Method	Based on Equipment	% MTBF Improvement
WD (When Discovered) (By deleting failures discovered during non-operating period)	All Six Equipments	22.7
	ARN-118 TACAN	8.6
	ARC-164 UHF Radio	12.3
DC (Duty Cycle) Regression Analysis	ARN-118 TACAN	29.5
	ARC-164 UHF Radio	2.8
MD (Mission Duration) Regression Analysis	ARN-118 TACAN	11.6
	ARC-164 UHF Radio	-3.4

some failures that occur during nonoperating time are not detectable while the aircraft is on the ground, hence, they are counted as operating failures even though they may have occurred during nonoperating time. The ratios estimated for the ARN-118 TACAN and the ARC-164 UHF radio by means of the duty cycle analysis method were found to be 41 and 73 respectively, compared to 188 and 132 with the When Discovered (WD) method.

The following conclusions and recommendations have been derived from this study:

Conclusions:

1. Nonoperating failures have a measurable effect on assessed operational MTBF of avionic equipment. For the equipments studied the average non-operating failure contribution is approximately 10 to 30 percent of the total number of failures for typical utilization rates of 20 to 60 hours per month. Therefore, it is imperative that only operating failures be counted in mission-oriented failure rate determination.

2. Field nonoperating failure rates cannot be predicted to a reasonable degree of accuracy using any of the established prediction methods. The data for the six equipment types investigated preclude the establishment of consistent relationships between predicted and measured nonoperating failure rates.

3. The analysis results did not verify the current belief that microelectronic parts have a lower ratio of operating to nonoperating failure rates than other types of parts. This finding, however, may be due to a number of other variables affecting the data on which this study was based.

4. Environmental severity factors (ESFs) appear to be both equipment and platform dependent. This indicates that the development of only average ESF or similar factors, such as π_E, for all types of avionic equipment may give very erroneous results with respect to a specific equipment type.

Recommendations:

1. Any study of the effects of environmental stress on avionic equipment failure rates should also consider the influence of other factors such as equipment function and maintenance policy on the equipment's field failure rate.

2. Age has a significant influence on the magnitude of the failure rate at any point of time. Therefore, effects of age must be normalized in any failure rate studies that involve equipments having a variety of ages.

3. To permit more meaningful inferences to be drawn from the data base used for studies of this type, future studies should be planned to include equipments with the following characteristics:

   a. Relatively uniform and constant equipment/platform combination population throughout the study period so that variation due to equipment age and flaw removal rates can be minimized.

b. Each equipment type should be on several different aircraft types (more than four if possible) for each category (bomber, fighter, etc.) of interest in which the equipment is used.

c. The equipment types selected should have a uniformly distributed range of complexity to prevent biasing of analysis results by equipment with extremely high or low complexities.

4. Differences in the maintenance action documentation procedures as implemented by the various operating commands and/or bases should be further investigated so that the influence of the documentation procedural differences can be accounted for in the performance assessment process by those using maintenance data collection system (MDCS) data for studies similar to the one reported on herein.

1.0 INTRODUCTION

1.1 BACKGROUND

1.1.1 Lack of Correlation Between Three Measures of Avionic Equipment Reliability

The apparent lack of correlation between predicted, demonstrated, and field reliability of avionic equipment has been a matter of concern to the Air Force for some time. The results of a number of recent studies (References 1 through 5) indicate predicted MTBF to be between five and 50 times greater than field MTBF. When comparing the demonstrated to field MTBFs, the corresponding ratios are between 3 to 1 and 20 to 1.

1.1.2 Contributions of Hughes OIR Study

1.1.2.1 Causes of the Lack of Correlation

A previous study performed by Hughes Aircraft Company for RADC entitled Operational Influences on Reliability (OIR) identified the causes of this lack of correlation and established quantitative relationships between the three values (References 6 through 9). The results indicated that the differences were due to a combination of definitional factors (i.e., what is a failure, what is the time base?) and operational factors. Significant differences in operational reliability were observed between equipment installed on fighter/interceptor aircraft and on heavy bomber/transport aircraft, as well as between sets of the same equipment installed on different aircraft of the same type. Among the reasons for the differences, the definitional factors were found to be the largest single influencing factor. Some factors affecting predicted and measured failure rates are shown in Figure 1-1.

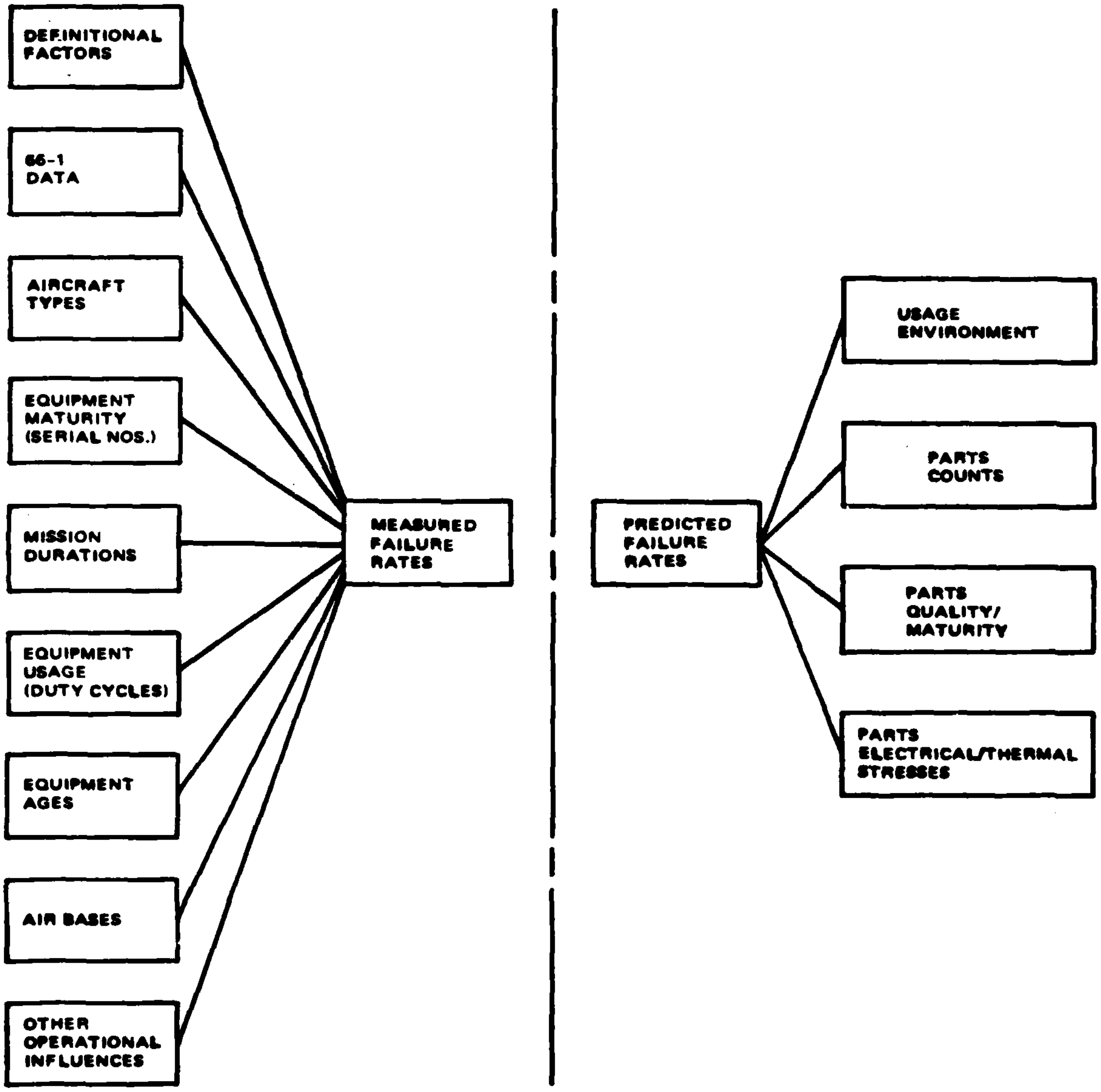

Figure 1-1. Factors affecting predicted and measured failure rates for avionics equipment.

Another area to be considered is that reliability predictions seem to be consistently higher than actual field operational reliability. Experience on the OIR study confirmed this, but what is generally not recognized by those who look critically at predicted values of reliability is that the predictions can indicate only what the inherent reliability of the mature hardware can be under a certain set of design and environmental conditions. Since the predictors have no control over a number of factors that can have a very significant impact on the actual value of the achieved reliability (such as the skill levels, logistic support resources, facilities, working and operating conditions and the degree to which design and software changes required for maturation are implemented), how could they be expected to do anything but predict an inherent reliability characteristic? Numerous questions were raised during the OIR study regarding the impact of nonoperating failures on the acquisition, development, user and logistics community. In response to these questions, the present study took on a considerably broader view than the originally stated objective.

1.1.2.2 Importance of Nonoperating Failures

The need for a better understanding of the characteristics and magnitude of avionic equipment failures accrued during nonoperating time was identified during the OIR study. The reason for interest in this parameter was that the method used by AFLC for assessing equipment MTBF is based on the count of all failures (regardless of when discovered) divided into equipment operating time. Some fraction of these failures may have occurred during nonoperating time. The resultant value of assessed MTBF, therefore, tends to be lower than the value of operating MTBF that would be obtained if only those failures that occurred during the operating time of interest are included.

Although the nonoperating failure rates may be only a small fraction of the operating failure rates, e.g., 1/20th, the relative amount of time accrued in the nonoperating state is about 20 times greater than the operating time. Therefore, the assessed MTBF in the field could easily be doubled if only operating failures and operating time were included in the assessment of field MTBF.

1.1.2.3 <u>Quantitative Effect of Nonoperating Failures</u>

A nomograph was developed during the OIR study (Reference 6) which will help visualize the relationship between the operating/nonoperating failure rate ratio of an equipment. The nomograph also helps visualize how the distribution of the relative failure fractions (expressed as a percentage of total failures) is influenced by the equipment's utilization rate.

The following rationale was used to derive the equation for calculation of the equipment operating and nonoperating failure contributions to the total failures observed during a given period of time. It is assumed that during the period of nonoperation, the equipment's primary environment is that seen while it is installed on the weapon system (aircraft) or undergoing maintenance.

Consider the following expressions:

$$\frac{\lambda_{OP}}{\lambda_{NOP}} = x$$

$$T_{OP} + T_{NOP} = 730 \text{ hours per month } \left(24 \frac{\text{hrs}}{\text{day}} \times \frac{365 \frac{\text{days}}{\text{year}}}{12 \frac{\text{months}}{\text{year}}} = 730 \frac{\text{hrs}}{\text{month}}\right)$$

$$T_{OP} = K(UR)$$

$$FOP = \lambda_{OP} T_{CP}$$

$$FNOP = \lambda_{NOP} T_{NOP}$$

$$FTOT = FOP + F\ NOP$$

where

λ_{OP} = Equipment operating failure rate (failures/hour)

λ_{NOP} = Equipment nonoperating failure rate (failures/hour)

x = Ratio of equipment operating to nonoperating failure rate

T_{OP} = Equipment operating time per month (hours)

T_{NOP} = Equipment nonoperating time per month (hours)

K = Equipment operating time/flight hours ratio

UR = Aircraft utilization rate (in flight hours/month/aircraft)

FOP = Number of equipment operating failures per month

FNOP = Number of equipment nonoperating failures per month

FTOT = Total number of equipment failures per month

Then to derive the relative contribution of operating failures to total failures expressed as a percentage,
let

$$\%_{OP} = \frac{100\ FOP}{FTOT}$$

Substituting these equations into the formula for the percentage operating failures ($\%_{OP}$) yields the following relationship between $\%_{OP}$, the ratio x of operating to nonoperating failure rates, the ratio K of the equipment operating time to flight hours, and the equipment utilization rate UR:

$$\%_{OP} = \frac{100\ x}{x - 1 + \frac{730}{K(UR)}} \qquad (1-1)$$

The relative contribution of operating and nonoperating equipment failures was assessed using the method described for failure rate ratios x = 10, 20, 40, 80, and 160:1. The range of values of the product of K and the equipment utilization rate used for the analysis was from 5 to 100 operating hours per month per equipment. These ranges encompass the range of values characteristic of the equipment included in the study. This resulted in the development of the nomograph given in Figure 1-2. The expected distribution of operating and nonoperating failures for a

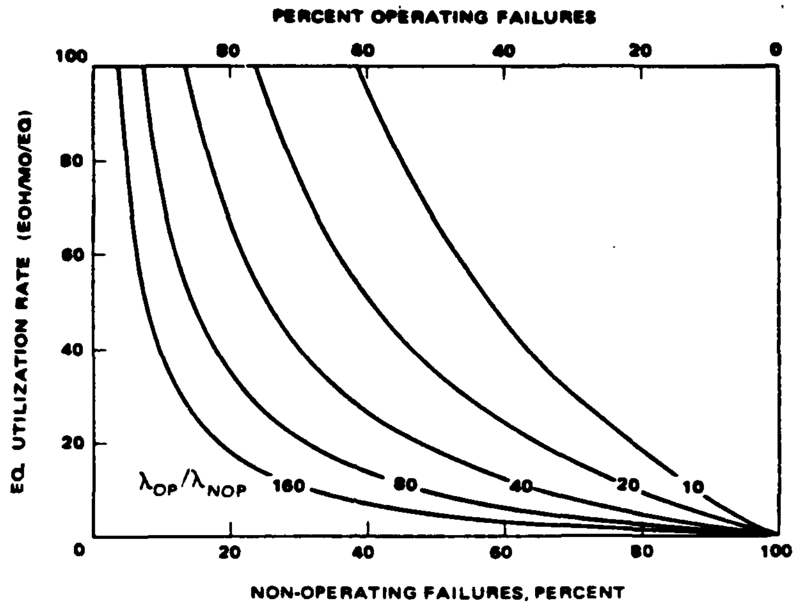

Figure 1-2. Equipment operating and nonoperating failure contribution.

given item of equipment can be estimated from Figure 1-2. The data required to use the nomograph are the equipment's utilization rate (expressed in equipment operating hours per month per equipment) and the ratio of the equipment's operating to nonoperating failure rates. Alternatively, the nomograph can also be used to derive the ratio of operating to nonoperating failure rates if the equipment's utilization rate and either the percentage of operating or nonoperating failures is known.

As technology advances toward more widespread use of solid state devices and microcircuits, the differences between operating and nonoperating stresses and temperature levels will become even smaller. Therefore, the failure rates pertaining to the nonoperating period may no longer be negligible which would increase the percentage of nonoperating failures even more as shown in Figure 1-2.

According to the commonly used method of MTBF assessment, the denominator of the equation

$$\text{MTBF} = \frac{\text{Operating Time}}{\text{Failures}}$$

includes all failures observed, without regard to the fact that some of the failures occurred during nonoperating time, the assessed MTBF value obtained tends to underestimate the true value of operating MTBF.

1.1.2.4 Effect of Nonoperating Failures on the Weapon System End User

From a standpoint of the weapon system end user (TAC, SAC, MAC, ADC or ATC), two parameters of prime interest are mission reliability and operational readiness. The AFLC derived value of mission reliability is obviously understated by the current method of assessment, and the impact of nonoperational failures on operational readiness is unknown, since the AFLC assessment methods do not include nonoperating failure rate in MTBF assessments.

Looking at the problem of avionic equipment failures from the logistic support (AFLC) viewpoint, the impact of failures on logistic support resources (in terms of demand on supply) is of prime interest. To make more meaningful and valid projections of logistic support requirements, a means of estimating support requirements for both the installed avionic equipment inventory and the supply inventory is desired. The term supply inventory includes the number of spare equipments in base and depot level supply. The maintenance data reported under the AFM 66-1 Maintenance Data Collection system (Reference 10) are not summarized to permit reporting demands on logistic resources generated during weapon system operating or nonoperating time and the data do not identify failed items found on removal from supply. Therefore, AFLC must rely on empirically derived methods for developing provisioning forecasts based on past historical records. With recent advances in electronics technology and the increasing complexity of avionic equipments, the methods currently used by AFLC for provisioning estimates could result in either overprocurement or underprocurement, depending on the item of interest.

1.1.2.5 OIR Study Recommendation

One of the key recommendations of the OIR study was to establish nonoperating failure rates for various types of avionic equipments. This recommendation led to the present study.

1.2 STATEMENT OF STUDY OBJECTIVES

The primary objectives of the Nonoperating Failure Rates for Avionics (NOFRA) study were:

1. Investigate the existence and magnitude of nonoperating failure rates for avionics
2. Establish the significant influencing factors by which nonoperating failure rates are affected
3. Recommend methods for incorporating study findings into MIL-HDBK-217B.

More specific objectives of the study included: (1) Perform predictions for operating MTBFs of a representative mix of avionic equipments using the methods of MIL-HDBK-217B and compare the predictions with the results of field assessed MTBFs based on present measures of field reliability (using total failures) and/or field reliability considering only operating failures, (2) Determine the extent to which nonoperating failures affect the measured MTBF, and (3) Ascertain how parts mix affects nonoperating failure rates.

1.3 THE DEFINITIONAL PROBLEM OF NONOPERATING FAILURE RATES

1.3.1 Statement of the Problem

Any consideration of nonoperating failure rates must employ very carefully defined terms. A literal interpretation would be as follows: "The failure rate while the equipment is not operating." This leads to some difficulty since generally a failure cannot be observed without operating the equipment. A failure observed at the time of turn-on raises the question of whether it was due to turn-on or whether it had occurred at some unknown time before turn-on.

Assuming that these difficulties can be resolved, this interpretation must not make the inherent assumption that stresses during "operating" times contribute only to operating failure rates while stresses during "nonoperating" times contribute only to nonoperating failure rates. This, of course, is never the case. Any failure is the result of the cumulative exposure to stresses applied over the total previous history of the unit. Furthermore, fatigue studies show wide variations in the cumulative stresses required to cause a failure and show that the cumulative damage is a function of the order in which those stresses are applied. However, the concept of operating and nonoperating failure rates is a very useful artifice in commonly performed reliability analyses. If such an artifice yields a useful analytical result, it is an acceptable analytical tool.

If the equipment is found to have a discrepancy at time zero, the failure impacts weapon system mission capable rate, and it is immaterial whether the equipment failed at the instant of turn-on or at any time before turn-on. Regardless of when the failure actually occurred, the detection of a discrepancy at time zero has impacted on the mission capable rate. Had the failure not been detected until after the start of the mission, it would have impacted mission reliability and not mission capability. Hence, its classification as an operating failure would be appropriate.

1.3.2 Definitions Used in NOFRA Study

To clarify the terms "operating" and "nonoperating" time or failure, the following definitions are used in the NOFRA study:

1. Operating time is the time during which the avionic equipment is energized and is performing its function, either on or off the aircraft, either in support of the mission or during the performance of maintenance activities.
2. Nonoperating time is the time during which the equipment is in its normal installation configuration, fully connected but not energized or otherwise operated. Also included in nonoperating time is the time an equipment accrues in either a base or storage depot level supply status, not connected to a system, and during which time it experiences a somewhat more benign environment than when installed (but nonoperating) on the weapon platform (includes transportation and handling).

During the study, it became apparent that the meaning of nonoperating failure rate depends on how it is defined. This problem stems from many factors such as failure detectability, test thoroughness, maintenance policy implementation, data recording procedures, and the necessity for turning on the equipment to detect a failure. It became clear that the calculation of nonoperating failure rates (or whatever one might call it) is entirely dependend on the ultimate use of the rates. For mission reliability purposes, nonoperating failure rate could encompass all failures that occurred outside of the mission time. For logistics and maintenance optimization, it is necessary to know the equipment's failure rate when it is not operated or in storage. Therefore, in this study, nonoperating failure rates were derived using several methods. The values and ratios of both operating and nonoperating failure rates are presented in the section entitled Summary of Analysis Results.

All terms used in this report are as defined in MIL-STD-721A (Reference 12) unless a more specific definition is given in Section 7.0 titled "Definitions" of this report. Whenever reference is made to flying hours, sorties, or mission duration, these terms are as defined in AFM 65-110, Aerospace Vehicle Status Reporting (Reference 13).

2.0 APPROACH

The major elements of the analytical tasks are illustrated in Figure 2-1 in the form of a study flow diagram. The data flow begins with the acquisition of the AFLC field data pertaining to each of the equipments and weapon systems included in the study. These data and data retrieved from Hughes' data files on the equipment and weapon platform characteristics were then organized, validated, and reduced to develop the data baseline. An added input to this data baseline was the predicted MTBF value resulting from the new baseline prediction based on MIL-HDBK-217B. A literature search provided the latest information on models and factors affecting failure rates. The most notable findings from the literature search included several reports dealing with the environments to which avionic equipments are exposed and their effects, and the effects of equipment age and mission duration on failure rates. Several different approaches were used to quantify the nonoperating failure rate characteristics of the equipments included in the study. These approaches included direct quantification based on maintenance data analysis (measured failure rates based on When Discovered codes) and indirect quantification using regression analysis methods in which mission duration, duty cycle, and parts mix were used as the variables of interest. Data vectors in terms of matrices were developed based on the available data and the requirements from the models. Following this, statistical analyses were performed leading to development of nonoperating failure rate indicators. All the data and the findings from the investigation were then compiled into this final report.

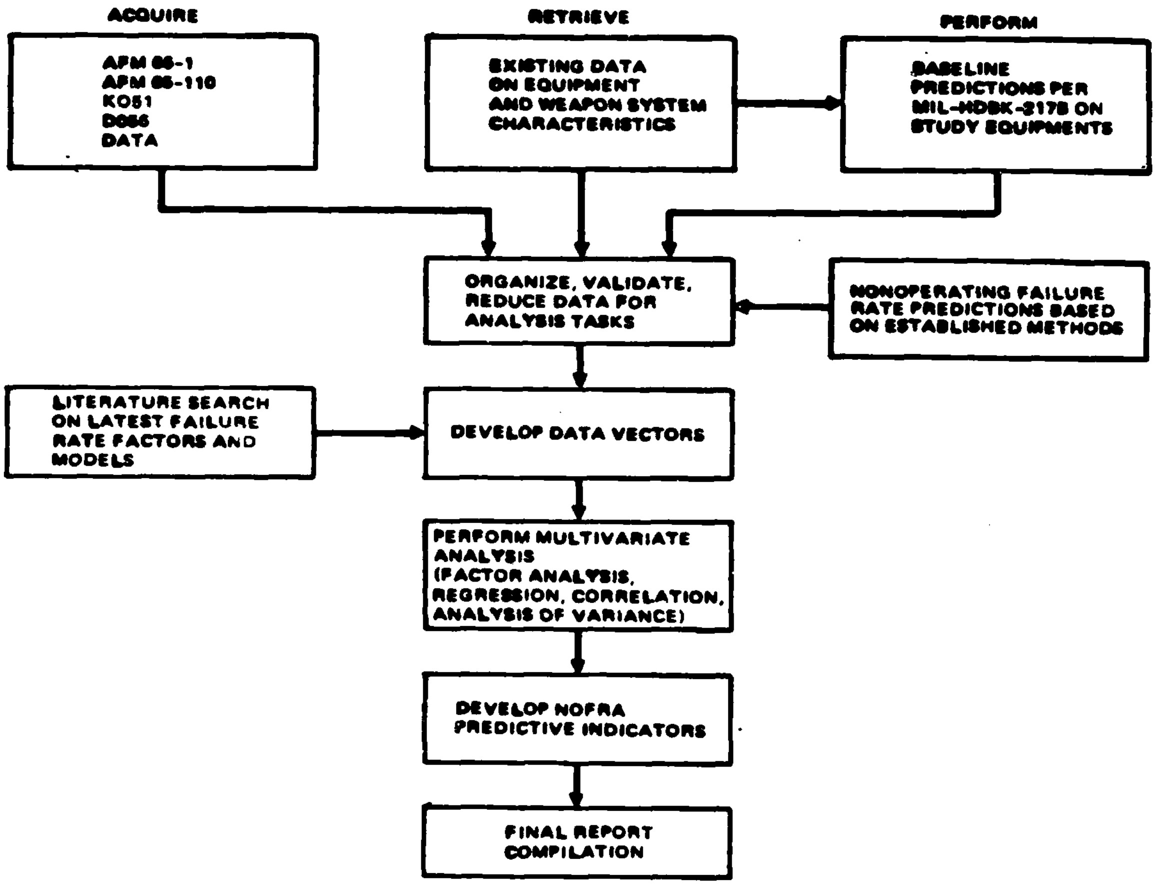

Figure 2-1. Flow diagram for NOFRA study.

These elements are described in the following sections. The data collection is described in Section 3.0 and the data analysis is described in Section 4.0. The analysis results are summarized in Section 5.0 and the conclusions and recommendations are presented in Section 6.0.

3.0 INFORMATION BASE

3.1 EQUIPMENT SELECTION

A representative matrix of avionic equipments and aircraft weapon platforms was developed for establishing the equipments to be included in the NOFRA study. The criteria used for equipment candidate selection were similar to those developed for the OIR study, and were:

1. Equipment must be of recent vintage; as defined herein, this means post 1970.
2. The design of the equipment must be characteristic of latest technology in circuits and packaging techniques.
3. The equipment must be used by a large segment of the Air Force.
4. The equipment must have a high population.
5. The equipment selection should represent a broad cross section of the Air Force avionic application.
6. The equipment must be one designed and developed under a contractual reliability program plan.
7. The equipment must be one on which AFM 66-1 Data Products (Reference 14) and IROS Reports (Reference 15) are available.
8. The equipment should be one on which MIL-STD-781 (Reference 16) reliability demonstration tests were conducted.
9. The equipment should be of such maturity that the using commands are thoroughly familiar with it, and there is no learning curve problem in maintenance or use.

Additional requirements to which the selected avionic equipments were developed are included in specification MIL-E-5400 (Reference 17) and MIL-STD-704 (Reference 18).

The final selection of equipments consisted of six different equipments representing different applications on fighter, interceptor, attack, bomber, transport, tanker, and trainer aircraft. Since several of these equipments are used on two or more different weapon systems, a totoal of 32 different applications (combinations of equipment and weapon system) are included in the study.

The number of equipments selected was limited by the available resources (manhours) required to perform the new predictions and compile/ reduce the field operational data. The specific equipments (identified as 01 through 06) included in the NOFRA study, and the weapon platforms on which they were used are shown in Table 3-1.

TABLE 3-1. EQUIPMENT/WEAPON PLATFORM MATRIX

Equipment	Weapon Platform Types																
	Fighters/Interceptors											Bombers/ Transports					
	A-7D	A-10	F-15	F-100	F-101	F-111A	F-111D	F-111E	T-37	T-38	T-39	B-52D	B-52G	B-52H	C-130	KC-135	C-141
1. ARN-118 TACAN	X	X				X	X	X		X	X	X	X	X	X	X	X
2. ARC-164 UHF Radio	X	X		X	X				X	X	X	X	X	X	X	X	X
3. AAQ-6 FLIR													X	X			
4. C-1108 Video Monitor													X	X			
5. AYK-12 Computer			X														
6. ARN-131 OMEGA Nav.															X		

This matrix represents equipments and weapon platform combinations that provide a data set which represents the different avionic functions across the two dominant platform types (fighters versus bombers) which were identified as having significant differences by the OIR study results. Furthermore, this selection is much more recent (1973) than used on the OIR study (1969), and provides a composite data matrix including more than 26 applications of the six equipment types on 17 different weapon platforms for the data base used on the NOFRA study. This matrix includes two avionic equipments from the OIR study and four new equipments, based on the same selection rationale as was developed on the OIR study.

Two of the equipments selected, the ARN-118 TACAN and the ARN-131 OMEGA Navigational Equipment, were developed and produced under RIW (Reliability Improvement Warrantee) type contracts. Because the manufacturers implement considerably more detailed data collection and analysis programs than is normal AFLC practice, it was anticipated that the manufacturer's data on these two items could be used to augment the AFLC data on these equipments for analysis purposes. References 19 through 23 give additional information on RIW procurements and discuss some of the additional reporting requirements and potential problem areas.

The selection of equipments was also influenced by the desire for a reasonable balance between the two dominant weapon platform types (bomber/tanker versus fighter/interceptor). A second matrix indicating the distribution of the equipment applications by weapon platform type is shown in Table 3-2.

Since the data on the installed inventory of equipments 01 and 02 (ARN-118 TACAN and ARC-164 UHF Radio) were not available by individual B-52 MDS type, the three applications (B-52F, B-52G and B-52H) were treated as a single data point, hence a total of only four data points are indicated in the subsequent analysis tables for the B-52, C-130, KC-135 and C-141 aircraft types. Similarly, the data for the TACAN installations (equipment) on the F-111A, E and F models were treated as a combined data point, resulting in only five data points for the fighter applications representing the seven applications listed in Table 3-1. As can be seen, the resultant balance consists of 13 bomber/tanker and 13 fighter/interceptor platform applications.

TABLE 3-2. EQUIPMENT/WEAPON SYSTEM COMBINATIONS

Weapon Platform Type	Equipments						
	01	02	03	04	05	06	Total
Bombers	4	4	2	2	1	-	13
Fighters	5	7	-	-	-	1	13
Total	9	11	2	2	1	1	26

Because of the need for additional data with which to characterize avionic equipment failure characteristics, data on two additional equipment types (07, 08) taken from another related study program were also analyzed. The data on these equipments are included in the analysis data matrix as additional information, even though they were not included in the originally required data set and their use did not prove helpful.

3.2 TYPICAL AVIONIC EQUIPMENT FIELD CHARACTERISTICS

To better understand the type of service exposure avionic equipment must withstand, several aspects of the environments to which the equipments are subjected should be reviewed. This should enable the reader to develop a better understanding of the true cyclic nature of the avionic service environment, as well as a practical understanding of some of the more significant differences that preclude extrapolation of experience based on electronic equipments in other use environments.

Dealing first with the broad aspects of maintenance, the equipment is not subjected to an ideal environment because the available skill levels, motivation, training, technical manuals, maintenance facilities, and logistic support resources are far from ideal. An excellent report on the subject (Reference 24) discusses the ramifications of these factors based on a recent field study by an ASD team. The report also gives some excellent comments on the nature of the data reflecting avionics maintenance experience and some of the weaknesses in the MDC system. Also noted is the fact that when avionic equipments are operated during the performance of maintenance on the ground, they are sometimes exposed to more severe thermal environments than those normally encountered during flight. The report also points out that because of ambiguities and/or suspect performance of the built in test (BIT) function, maintenance personnel frequently are forced to resort to excessive removal and replacement actions or cannibalizations to restore a faulty system to an operational status. These excessive maintenance actions have a negative effect on the reliability of the avionic equipment.

A recent study by Grumman Aircraft (Reference 25) discusses the influence of environmental profiles on reliability demonstration. Among the more interesting information in this report is a table which lists more than 30 different potentially degrading environments and their probable effects on avionic equipment performance. For reference this table is included as Table 3-3. The significant point to be remembered is that most of the environments and their effects are equally applicable to the nonoperating part of an avionic equipments' use cycle when installed on the weapon platform.

Another interesting report published by AFFDL entitled "Combined Environments Reliability Testing of the AN/ARC-164 Radio Set" (Reference 26) contains quantitative mission profile data that given a good indication of typical values encountered during flight on an A-7D aircraft by the ARC-164 UHF radio. Several of the A-7D mission profiles are included in Figures 3-1 through 3-4.

In addition to the environmental profiles during flight, avionic equipments are also subjected to daily variations in temperature, humidity, airborne contaminants, etc., while the aircraft is on the ground. Depending on the geographical location of the aircraft, these temperatures can easily reach +155°F when the aircraft is parked in the sun with the canopy and bay doors closed, or an overnight low of 70 to 80°F at high relative humidities, and can form heavy condensation on the exposed surfaces of aircraft in the southwestern desert regions of the United States. Alternatively, the extreme cold temperatures seen in the Arctic regions, typically -40°F at night are not unusual for aircraft parked in exposed areas. Examples of these daily temperature variations for missiles under similar daily temperature cycles are given in Figures 3-5 and 3-6. The examples are from a MICOM report (Reference 27) on missile storage reliability factors. Although the MICOM report deals with missile system components, the discussion of environments and failure mechanisms is also applicable in many respects to avionics. However, these findings should not be extrapolated to other use environments because of the fundamental differences that are unique to each of the different use environments and the design approaches and constraints used for each.

The available literature dealing with dormant operating and storage effects (References 27 through 35 inclusive) deal primarily with missile system components and their respective environments. There are fundamental

TABLE 3-3. POTENTIALLY DEGRADING ENVIRONMENTS AND PROBABLE EFFECTS ON AVIONIC EQUIPMENT

Environment	Condition (Type)	How Manifested	Principal Effect	Probable Failure Mode
Temperature	Steady State-High	Ambient exposure Equipment induced Mission induced (certain steady state phases)	Aging Insulation deterioration Oxidation Expansion Reduction of viscosity Softening Evaporation, drying Chemical changes	Alteration of properties Shorting Rust Physical damage, increased wear Loss of lubrication in bearings, seizing Physical breakdown Dielectric Loss
	Steady State-Low	Ambient exposure Mission induced for certain phases and certain equipment Note: This condition is minimal. Encountered at present active bases, and in some flight modes	Contraction Viscosity increase, embrittlement, ice formation	Wear, structural failure, binding Loss of lubricity Structrual failure, cracked components Structural failure, alteration of electrical properties Loss of resilience - seal leaks
	Thermal Cycling	Ground operation Mission operation and profile environment control system limits	Decrease in component reliability	Repeated stress vibration causes mechanical failure of components solder joints, lifting of I/C's from base material.
	Thermal Shock	Mission profile Geography and season of year	High temperature gradients	Mechanical failure • Cracks • Rupture
Vibration	Sine	Engine induced-Propeller aircraft	Force variation Periodic variation (motion is harmonic) • Mechanical stress • Fatigue	Structural failure Increased wear Interference with proper operation Relay, switch contact chatter
	Random	Engine Induced-Jet Aircraft Acoustic Noise Turbulence (Aeronautical Buffeting) Gunfire	Force variation (Random variation of amplitude and frequency Pressure loads and force • Mechanical stress • Fatigue	Same as Sine
Contamination	Sand and Dust	Sand lifted by wind. Dust particles present above desert areas and in atmosphere throughout world Note: Confined to 10ft (maximum conditions at 1500')	Abrasion Clogging Sticking	Erosion of surfaces. Increase wear (especially in combination with moisture - water, oils, greases). Functional interference, arcing of high-voltage electrodes.
	Atmospheric Pollution	Chimney smoke Milling operations Volcanic action	Same as Sand and Dust, except formation of acids-in combination with mist.	Same as Sand and Dust plus extensive effects of acids
Explosive Atmosphere	Combustibles	Presence of combustible (fuel) gases inside equipment at temperature, R.H., and atmospheric pressure which favor explosion	Structural, etc. damage and/or complete destruction	Function interference. Loss of aircraft
Shock		Arrested Landing - Catapult Launch	Same as vibration	Same as vibration
Acceleration	Steady State	Catapult Launch - Maneuvers Due Mission Profile	Mechanical stress Induced switching, etc.	Loss of mechanical strength Interference of (relays, switching, centrifugal devices)
Fungus		High R.H., optimum temperature (100°) plus nutrient material (Tropical Environment)	Attack on organic materials	Loss of dielectric strength Electrical degradation
Bench Handling	Shock	Handling during shipping, installation, repairs, etc.	Structural damage Mechanical stress	Component damage, functional interference Electrical degradation (shorts, misalignment).

Reprinted from RADC TR-75-242 (Reference 25).

(Table 3-3, concluded)

Environment	Condition (Type)	How Manifested	Principal Effect	Probable Failure Mode
Atmospheric Electricity	Static	Autogeneous-Rubbing of particles (snow, dust, sand) against vehicle surface. Exogeneous-High potential Gradients in atmosphere.	Personnel shock Combustibles-ignition Arcing Radio interference	Interference with duty Explosion (See explosive atmosphere) Shorting - component damage primarily semiconductors Mission interference
	Lightning	Difference in electrical potential between ground and clouds or cloud to cloud (within thunder clouds)	Surface damage, complete destruction of non-metallic parts. Electrical damage	Loss of control surfaces Explosion of radomes, windshields. Current fed to electronic equipment from antenna causes equipment and component damage.
Radiation	Solar (Sunshine)	Heat energy leaving sun	See Temperature	See Temperature
	Cosmic	Sun, other sources. These are rays with enough energy to reach earth	Short term ionization. Generally no serious effects.	Spurious electrical pulses which may affect computers.
	Nuclear	Nuclear engines, nuclear reactors, nuclear weapons	Since frequency of occurrence is almost nil, this environment will not be considered.	
Transportation	Land Truck Rail	Shipment of equipment Delivery of equipment	In general the effects can be established from other basic environments i.e., temperature, altitude, vibration, shock, etc.	See individual environmental Temperature Altitude Vibration Shock
	Air Conditioned compartment Non-conditioned compartment	Shipment of equipment.	However, for air transport at 50K, a temperature of -105°F can be experienced per AT 70-38 (Army regulation)	Susceptible equipment can be physically damaged even in the non-operating-storage state.
	Sea			
Moisture	Humidity	Water content of air	Galvanic action Microbiological growth Electrolysis Moisture absorption Corrosion	Loss of electrical properties Interference with function swelling rupture Dissolution of metals Increased wear Fungus growth and material damage
	Condensation	Variation in altitude causes condensation on structure and within equipment.	Same as Humidity	Same as Humidity
	Rain	Precipitation of water vapor	Same as Humidity plus physical stress erosion	Same as Humidity, plus physical damage erosion
	Icing	Liquid droplets present at sub-freezing temperatures. Supercooled clouds.	Physical stress Added weight changes in aerodynamic profile	Structural failure Physical and electrical property changes loss of performance or even entire aircraft Interference with certain functions
	Hail	Developed in thunderstorms	Physical damage	Dents, cracks, ingestion
	Salt Fog -- Salt Spray	Salt in suspension in water droplets, coastal areas, ocean atmosphere. Shipboard environments, high winds, etc., creating salt water spray.	Corrosion Electrolysis	Increased wear Dielectric loss Structural defects • Surface deterioration Increased conductivity
Pressure	Ambient	Altitude Variation	Outgassing force due to pressure differential. Reduced dielectric strength of air	Loss of lubricants Structural damage Corona discharge causes ozone formation and damages parts, causes insulation breakdown. Ozone oxidized, rubber and synthetics also forms corrosive acids.
	Explosive Decompression	Instantaneous loss of cabin compartment pressure	Large instantaneous pressure difference.	Mechanical damage and pressure shock to equipment
	Wind	Differences in atmospheric density, producing horizontal difference in air pressure	Causes other environment to become dangerous. Sandstorms, blizzards alters flight paths of vehicles.	Primarily affects aircraft level. On ground could affect ground support equipment

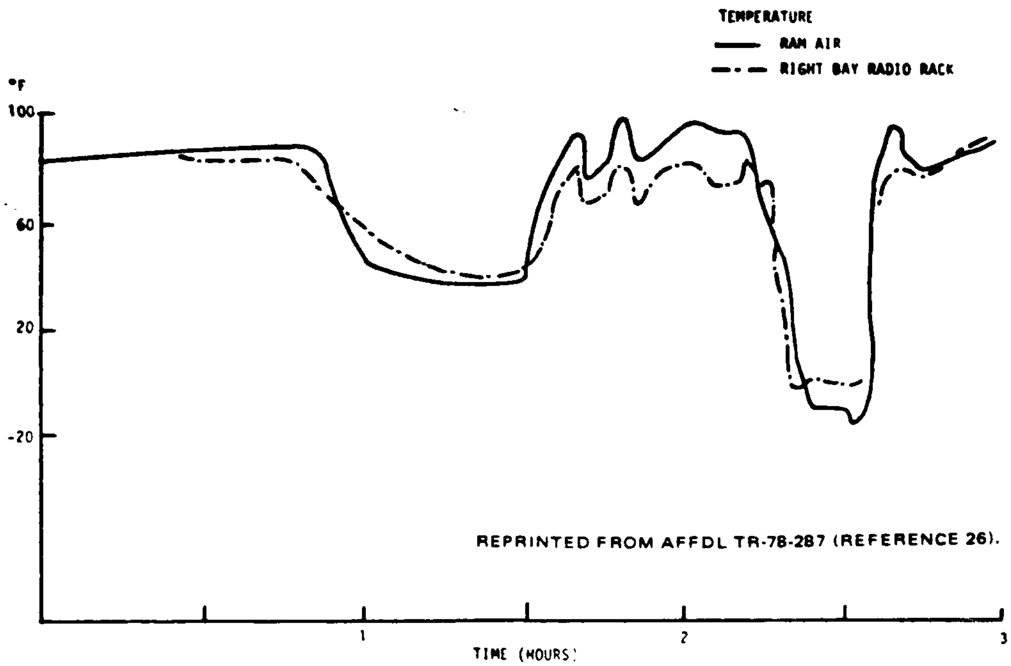

Figure 3-1. A-7D tropic flight measured data, right avionics bay.

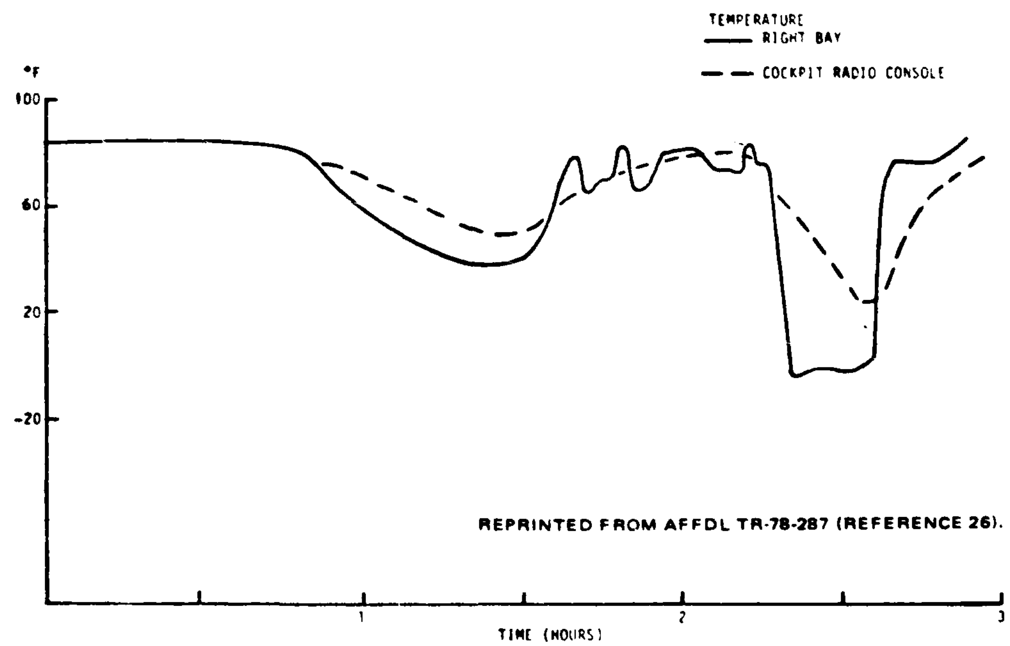

Figure 3-2. A 7D tropic flight measured data, cockpit radio location versus right bay.

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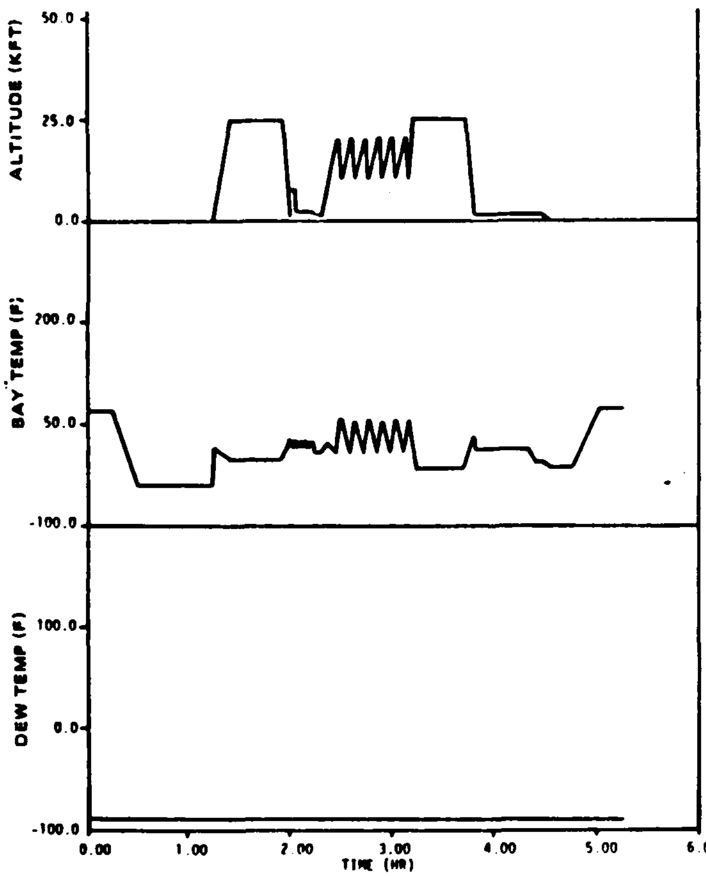

Figure 3-3. Arctic environmental mission profiles.

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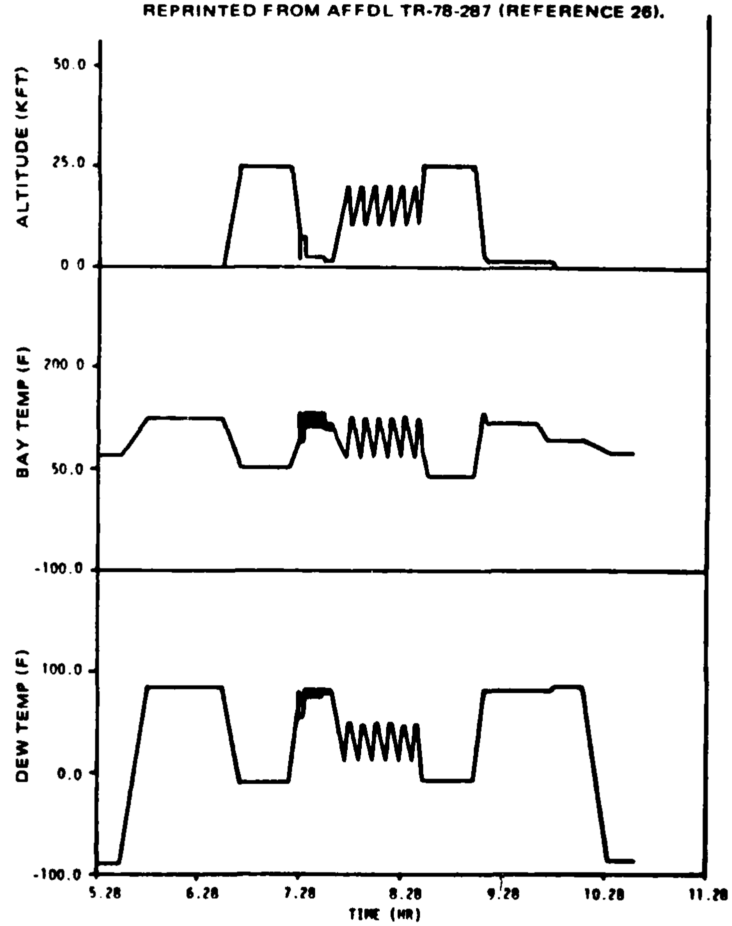

Figure 3-4. Tropic environmental mission profiles.

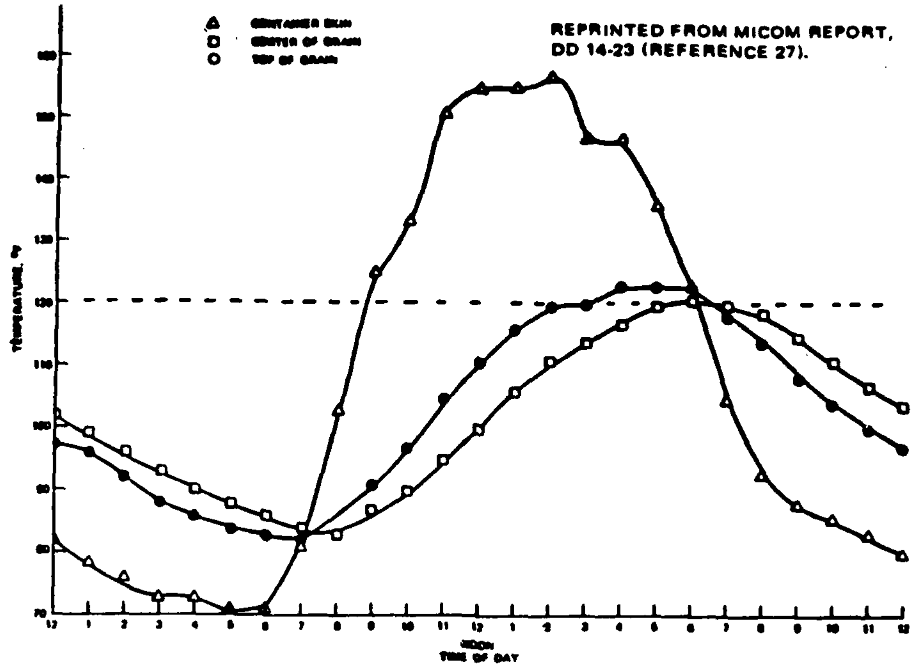

Figure 3-5. Temperature profiles of SPARROW motor in shipping container for 31 July 1979.

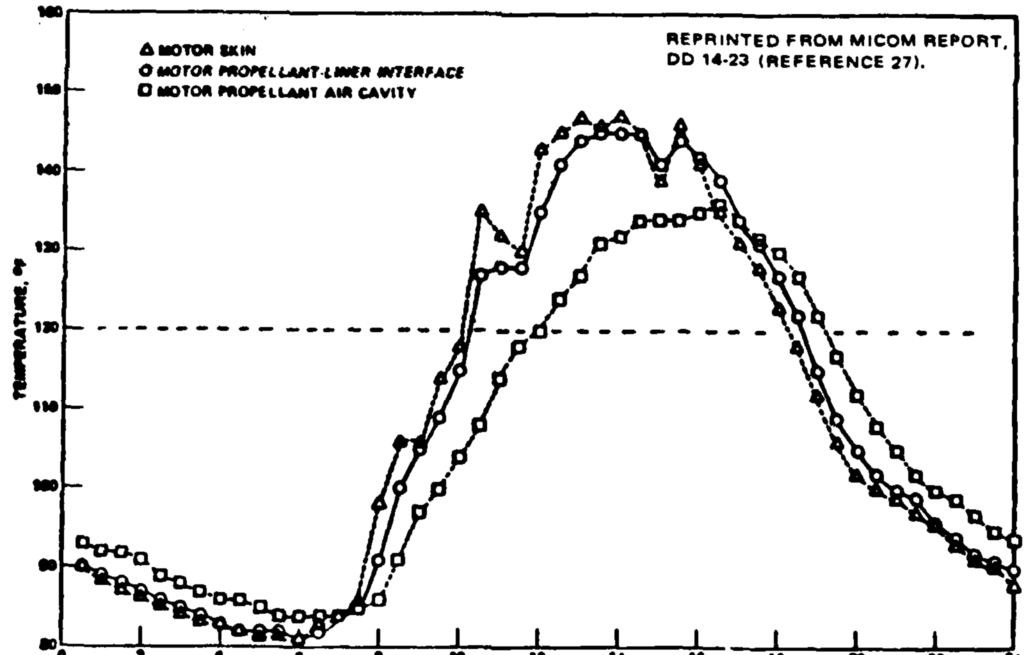

Figure 3-6. Diurnal temperature cycles of a CHAPARRAL missile, 1 August 1973. Temperature readings at three indicated locations.

differences in the design requirements, objectives, testing, and environments, etc., of missile system components viz-a-viz avionic equipment components. Therefore, a rationale cannot be developed on the basis of which failure rates can be extrapolated from missile system use environments to avionic equipment use environments.

The reasons for the foregoing become more apparent when the differences in use requirements are considered. Missiles are generally designed for prolonged periods of protected storage during which little or no testing is performed, followed by a one-shot operational mission. Avionic equipment is designed for 10 to 15 years of intermittent use on aircraft, during which time many cycles consisting of operation during the mission followed by a period of nonoperation between missions are accumulated. During its service life, the avionic equipment is subjected to numerous testing and repair cycles, some of which may include shipment back to a repair depot half way around the world.

Analysis of avionics equipment maintenance data collected and analyzed for this study indicates that an avionic equipment's cumulative environmental life cycle exposure profile between failure occurrences is between 15 and 160 use cycles. Each use cycle consists of between 1.2 to 8 hours of operating time during a flight mission, followed by a nonoperating period that may range from as little as one-half hour to as long as 90 days. During this period, the avionic equipment item will have been subjected to an additional number of on-off cycles of shorter duration while maintenance is being performed during ground operating time on the weapon platform. There is a 0.9 probability that the equipment will have been removed from the aircraft each time a failure occurs, sent to the base avionic maintenance shop for repair, and subsequently returned to base supply following repair. The equipment may spend the next several days or months in base supply, depending on the resources allocated to the base. Alternatively, between 2 and 20 percent of the removed LRUs (line replaceable units) are sent to a repair depot for corrective maintenance. In the interim, the aircraft continues to fly its missions with a replacement avionic unit of like type that has also circulated through the complex supply system from the manufacturer to the depot, from the depot to airframe prime contractor or base, from base supply to the base avionics maintenance squadron (AMS), from the AMS to the aircraft weapons platform or the depot, and/or from the aircraft weapon platform back to the AMS.

On the average, the equipment will have experienced one failure during this time interval (15 to 160 cycles), and it would be difficult to ascribe the failure to a specific environmental cause. On the other hand, the AFLC maintenance and operational status records (AFM 66-1 and AFM 65-110 data) could be interrogated and used to identify when and where the failure was discovered, thereby permitting classification of the failure occurrence as a function of its impact on mission reliability, mission capability, or base or depot supply resources.

There is good evidence to support the fact that the nonoperating environment of the equipment when installed on the weapon platform is considerably more severe than when the equipment is exposed to the depot or base supply environment. It is, however, an academic point since the equipment item, at the actual time of failure, has failed as a result of the cumulative effect of its previous environmental exposures. This cumulative exposure effect consists of many individual sequences of turn-on, operation, turn-off, and non-operation, so that the precise instant of failure occurrence cannot, in reality, be ascribed to either operation, non-operation, or the turn-on or turn-off interval. It might be considered (in the absence of a pattern failure process) that the actual interval during which the failure occurs is in fact a randomly distributed function.

In any event, the end effect of the failure occurrence is the real point of interest, and this can be categorized as being either "mission" significant or "operational readiness" significant in the broad sense. The mission significant category includes all failures that occur after the weapon system is committed to a mission, having successfully completed a pre-flight functional check by the aircrew. The operational readiness significant category includes all failures discovered between flights or during the preflight checks by either the groundcrew or aircrew which cause the system to be classified as Not Mission Capable due to a requirement for corrective maintenance (NMCM). Note that there is another closely related category, Not Mission

Capable due to lack of supplies (NMCS), which also can affect the mission capable rate of the weapon system that is logistic supply related, and not directly attributable to failure.

In summary, it is seen that there is a myriad of environments and environmental interactions to which avionic equipment is exposed during its service life cycle. These environments vary from relatively benign long term storage to extremely severe environmental exposure during operational use and/or the exposure it receives during transportation, handling, unpacking, testing, disbursement, installation on the aircraft, and the performance of subsequent maintenance actions. Considering the differences in operational requirements and policies amongst the various operating commands, which have a direct impact on maintenance policies and their implementation, it is not at all surprising that considerable variation in the field performance of the same equipments and/or evidence of induced damage during the performance of maintenance are prevalent. Therefore, the separation of individual encironmental factors such as temperature, vibration, humidity, temperature rate of change, etc., and the quantification of the effects on failure rate of these sub-elements of the combined environments becomes an impossible task.

3.3 FIELD OPERATIONAL DATA COLLECTION

This study was based on the use of available historical data pertaining to the required, predicted, and field operational reliability performance of selected items of avionics equipment. The data used were obtained after investigation of a variety of data collection and analysis programs. These AFLC data systems (AFM 66-1, AFM 65-110, K051, and DO56) are the same as those used previously on the OIR study. The data sources were distributed among the developing (AFSC), supporting (AFLC), and operating commands (ADC, ATC, MAC, SAC, and TAC).

Maintenance and operational use data on avionic equipments in the current operational inventories of the five major USAF Operating Commands (ADC, ATC, MAC, SAC, and TAC) on 19 different aircraft types have been collected, analyzed, and summarized at the LRU and equipment levels. Although it was desired to perform assessments at the component part type level also, it was not possible to do so for the following reasons: (1) The available data on parts reflects part replacement experience, and part replacement data cannot be related to part failure data; (2) The part replacement data cannot be related to the original discrepancy occurrence since the data required for traceability (serial number of equipment and/or original Job Control Number of the maintenance event) are not maintained in the data for the depot repair level, where the majority of parts replacements are made; (3) Judging from the fact that the data points at the equipment level hardly provide significant statistical data, it would be impossible to obtain sufficient data at the piece part level to show statistically justifiable conclusions.

All data pertaining to the field operational characteristics are based on the 1-year period ending 31 December 1978, and represent the total weapon system inventory performance of the equipment item of interest (i.e., total force performance values by weapon system MDS) while operated in the continental United States. The reason for this restriction is because data from overseas bases are not collected and subject to the same controls as data from domestic bases. These overseas data could adversely affect the quality of the data base as well as introduce other variables.

It is appropriate to list a warning at this point: Caution must be exercised when using data gathered for other purposes because of the inherent uncertainty which arises, i.e., the AFLC's MDC system was never intended to be used as a reliability assessment tool; it was designed to serve the needs of the logistic support community, and any inferences made relative to the reliability performance of hardware based on MDCS data must recognize the limitations of these data and the purpose for which they were collected.

The quality of data obtained varied widely relative to study needs, thereby imposing some limitations on the number of applications included in this study. Also, data on some of the desired factors were unavailable and consequently these factors could not be included in the final analysis. Nevertheless, although some weapon system applications of the equipments included in the study had to be dropped, the final data matrix characterizing the field experience consists of 26 combinations of equipment and weapon system (aircraft) type.

In addition to the data on the six equipment types included in the study, data on two additional equipment types were also collected and analyzed in an attempt to increase the data sample size and gain additional insights into the relationships being investigated on the NOFRA study.

Field operational reliability values were derived from AFM 66-1 MDC system data (Reference 10), from AFM 65-110 data (Reference 13), from K051 system data products (Reference 15), and from DO56 Product Performance System data products (Reference 14). Logistics performance factors were obtained using the methods described in AFLCM 800-3 (Reference 36).

The input data from AFLC DO56 and AFM 65-110 data files were extracted, validated, and entered into the computer file for analysis and derivation of the required factors using the same methods and analysis programs (software) developed for the OIR study. These data, once reduced and summarized, were used to derive the field operational factors such as operating time, nonoperating time, the number of failures and maintenance actions during both operating and nonoperating time periods, the flying hours, mission durations, and the utilization rates of each equipment/weapon system applications included in the study.

3.4 DATA BASE COMPILATION

The results of the field operational data collection and analysis task provided an ordered data file, containing the required factors for assessing the operating and nonoperating failure characteristics of avionic equipment at the equipment and LRU levels. All of the factors and parameters utilized in this study are defined in Section 7 entitled "Definitions."

The following paragraphs explain the methods used for deriving a number of the more important factors and parameters relating to equipment use characteristics for the items of interest to this study.

3.4.1 Classification of Field Failures

Each field failure was classified into either an "operating" or "nonoperating" failure by using the when discovered code (WDC) reported on the maintenance action record for each failure occurrence against a given work unit code (WUC) as shown in Figure 3-7. The WDC reflects when the failure was discovered (i.e., detected), and not when the failure actually occurred. Using these data for nonoperating failure rate calculations presumes that the period during which the failure occurred is the same as the one in which it was detected. This calculation will give an approximation to the nonoperating failure rate based on field maintenance data.

It should be recognized that some error in the assessed failure rates for operating and nonoperating categories may exist. This is because some failures that occur during nonoperating time while the aircraft is on the ground may not be detectable until after the mission begins, just as some failures that may occur during the mission may not be detected until the next check when the aircraft is on the ground. Discussions with operations and maintenance personnel regarding the possible error magnitude and direction

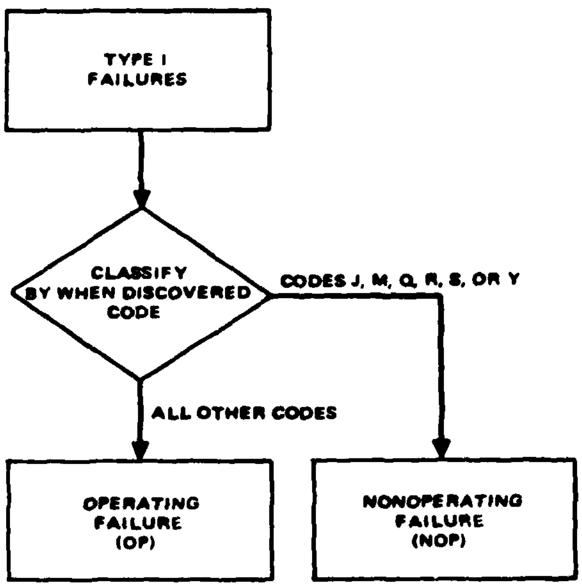

Figure 3-7. Operating vs. nonoperating failure classification.

indicate that the possible error would tend to cause the nonoperating failure rate to be somewhat lower than the true value. The magnitude of the error depends primarily on the degree to which it is possible to perform a valid functional test of a given equipment while the aircraft is on the ground.

Clearly, for some equipments such as a command radio, which is in use for some time before aircraft takeoff, functional failures or discrepancies would quite likely be detected on the ground. On the other hand, many failures of TACAN equipment or inertial equipments are not detectable on the ground, and hence these would almost always be detected during flight (and classified as operating failures) even though some of them may have occurred during operating time.

Since there are no other available data that report the actual time of failure on avionic equipments, and the study was limited to making use of existing data records, the WDC for each occurrence was used to classify failures into operating and nonoperating categories.

Analysis of the AFM 66-1 MDC system data records, using the Hughes developed analysis programs, permitted a rapid assessment to be made of the total number of operating and nonoperating failures for each equipment WUC by month and year, so that the pertinent summary statistics such as percent operating failures and percent nonoperating failures, and the respective values of MTBF, failure rates and failure rate ratios could be derived.

3.4.2 Equipment Use Factor Calculations

3.4.2.1 K Factor Calculations

For the equipments investigated the DO56 system gives values of 1.00 for their K factors (the operating hours to flight hours ratio), thereby causing the resultant D056 reported values of MTBF to be based on equipment flight hours, not equipment operating hours. An analytical method was used to derive the equipment K factors. This model was developed on the previously completed OIR study (Reference 6). This model takes into account the real-time elements that collectively constitute the total equipment operating time, and permits the derivation of an estimated K factor that is in close agreement with measured values.

The model for calculation of the equipment use factor (K) is

$$K = \left(\frac{MT + GT}{MD}\right) + 0.45 \left(\frac{MMHRS - (1 \times TMA)}{EFHRS}\right)$$

where:

MT = Mission operating time on equipment (Hours)

GT = Equipment ground operating time (Hours) per mission

MD = Mission flight duration (Hours)

MMHRS = Maintenance manhours on equipment (Hours) per year

TMA = Total on equipment maintenance actions (WUCXX level) per year

EFHRS = Equipment flight hours (Hours) per year.

The first term of the model, (MT + GT)/MD is the ratio of equipment operating time to flight time that the equipment accumulates during mission flight. The GT term accounts for the operating time that the equipment accumulates during the air-crew pre-flight checkout, systems startup, and ground taxi and run-up operations, as well as the time accumulated after landing during ground taxi, post-flight checks, and system shutdown. The specified values of ground operating times were obtained by reviewing the actual real time sequence of events from equipment turn-on to equipment turn-off with flight crews representing each of the different weapons systems included in the study.

Note that the equation developed provides a means for including the weapon system flying time and ground operating time variables, and that the equipment mission operating time can be less than the mission duration for those cases where an equipment is operated during only part of the mission duration. For those equipments included in this study, all equipments are on for the entire mission duration, hence MT = MD.

The second term of the model, 0.45 (MMHRS - (1 x TMA)/EFHRS) accounts for the equipment operating time accumulated while maintenance is being performed. The term (MMHRS - (1 x TMA)) is the adjusted value of maintenance manhours that represents the active maintenance manhours, which when divided by EFHRS yields active maintenance manhours per flight hour. The adjustment (1 x TMA) is necessary to reduce the total number of maintenance manhours by deducting 1 hour per maintenance action (non-productive time) from the total to derive the active maintenance manhours. The constant 0.45 is an empirical constant which represents the fraction of the active maintenance index during which the equipment is operating (i.e., 45 percent).

3.4.2.2 Mission Duration (MD) Calculations

Since the D056 system does not give mission duration values, these values had to be calcuated for each of the equipments and weapon systems included in the study. This was done so that the influence of mission duration on operational reliability could be assessed using the analytical methods developed for the study. The equation used for the calculation of average mission duration is

$$MD = \frac{FHRS}{Sorties}$$

where:

FHRS = Total annual weapon system flight hours
Sorties = Total annual weapon system sorties.

3.4.2.3 Utilization Rate (UR) Calculations

Since the D056 system does not give utilization rate UR (number of weapon system flight hours per system per month) values, these values had to be calculated for each of the equipments and weapon systems included in the study. This was done so that the influence of utilization rates on operational reliability could be assessed using the analytical methods developed for the study. The equation used for the calculation of average weapon system utilization rate is

$$UR = \frac{FHRS}{12\ (INV)}$$

where:

FHRS = total annual weapon system flight hours

INV = average annual weapon system inventory.

3.4.2.4 Derivation of Equipment Operating Hours (EOHRS)

The total annual equipment operating time (EOHRS) values were calculated based on the reported values of weapon system flight hours (FHRS) reflected by AFM 65-110 records, the number of equipments per aircraft (QPA), and the equipment use factor (K) which was explained in Paragraph 3.4.2.1. The model used for calculating time was as follows:

$$EOHRS = (FHRS)\,(QPA)\,(K)$$

These operating time values were derived for the 1-year data window for the period ending 31 December 1978. In those cases where the equipment of interest was not installed on all active aircraft of a given MDS (i.e., partial inventory installations), the annual operating time values were calculated using the ratio of installed inventory to aircraft inventory as a means of estimating the EFHRS for each month during the period of interest, and then summing the monthly values to derive the annual value.

3.4.2.5 Derivation of Equipment Nonoperating Time

The total annual equipment nonoperating time (NOPTIME) values were calculated based on an average month (of 730.5 hours) and the assumption that the number of equipments in the supply inventory were 10 percent of the number of installed equipments. This assumption was necessary because the required data on supply inventory by calendar month and weapon system MDS were not available. The consensus recommendations from the various invetory managers and system managers at the ALCs contacted during the study were that using a 10 percent factor would probably be more accurate than what could be achieved by a detailed inquiry.

Since the operating time values were calculated for the installed inventory as explained in Paragraph 3.4.2.4, and the installed inventory values were also known, the nonoperating time values were calculated using the following model:

$$\text{NOPTIME} = (12)\,(730.5)\,(\text{INV})\,(\text{QPA})\,(1.1) - (\text{EOHRS})$$

where INV, QPA and EOHRS are as previously defined.

3.4.2.6 Derivation of Equipment Field Reliability Characteristics

The methods used for the derivation of the field reliability characteristics of each equipment of interest used the classical model for derivation of monthly and annual values of MTBF according to the following formula:

$$\text{MTBF} = \frac{\text{Time}}{\text{Failures}}$$

where the values of time and failures are either for the total, operating, or nonoperating time periods. For purposes of analysis, the failure rate (λ, the inverse of MTBF) is used in the subsequent analysis section.

3.4.3 Assessment of Field Failure Characteristics

The field reliability assessments based on analysis of maintenance records for each of the 26 equipment/weapon system applications included in the study were performed using computer programs originally developed in support of the OIR study. These programs analyze AFM 66-1 MDC system data for any given combination of equipments and weapon systems and generate an output report for the desired time interval (in months) and period ending date (year/month). This field data analysis summary (FDAS) report includes all pertinent factors desired for each equipment item at both the LRU and equipment functional levels as identified by the WUC structure of each weapon system. An example FDAS report is included in Appendix B for the ARN-118 TACAN.

The criteria used for field reliability assessments are the same as are used by HQ AFLC for the DO56 Product Performance summary reports as defined in AFLCM 66-15 (Reference 14). The FDAS report is generated in three segments which report on total failures, operating failures, and non-operating failures, respectively, and contain all required factors for deriving the reliability characteristics in support of the NOFRA study objectives.

For purposes of reliability assessment based on MDC system data, the DO56 definition of a "failure" is based on classifying the data into one of three "Type How Malfunctioned" codes and then classifying all "Type 1 How Malfunctions" reported in combination with an action taken indicating repair, adjustment, or item replacement and one or more units produced, as a "failure." All remaining Type 1 How Malfunctioned actions are classified as "Other Type 1 How Malfunctions" and are not used in calculating MTBF. The definitions of "Type 1, 2, or 6 How Malfunctioned" Codes are

1. Type 1 — These codes indicate that the item no longer can meet the minimum specified performance requirement due to its own internal failure pattern.
2. Type 2 — These codes indicate that the item can no longer meet the specified performance requirement due to some induced condition and not due to its own internal failure pattern.
3. Type 6 — These codes indicate maintenance resources were expended due to policy, modifications, item location, cannibalization and other no defect conditions existing at the time maintenance was accomplished.

The method used for the classification of maintenance actions into "Failures" in the DO56 analysis system is illustrated in Figure 3-8.

The field operational performance characteristics (summarized in field data summaries) were analyzed and reviewed to extract data and to identify factors relevant to reliability performance, using the methods outlined in AFLCM 66-15 for the derivation of equipment MTBF. All data master records were checked to verify the validity of the factors used in the data analysis program, and to identify any anomalies or errors in the data base. As an adjunct to the analysis of MDC system data, a number of operational air bases were visited to establish direct contact with base level

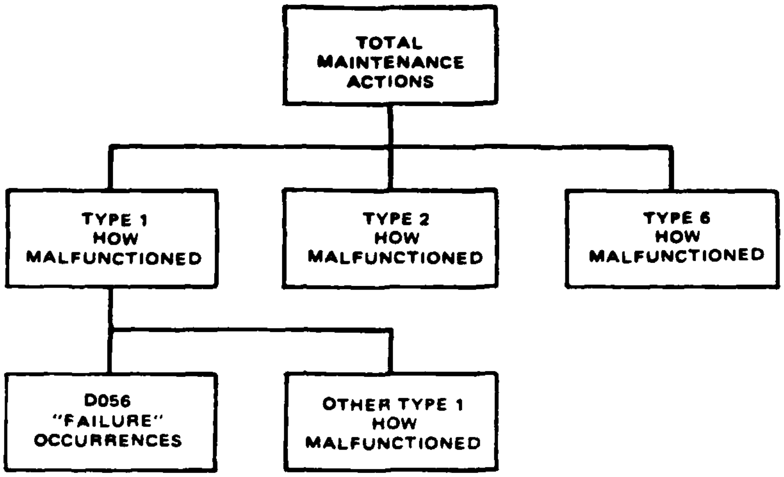

Figure 3-8. DO56 maintenance action classification.

avionics maintenance personnel, maintenance operations personnel, data management personnel, flight operations personnel, and quality control personnel.

Through these visits and the use of Hughes field service representatives at various other bases, a good understanding was developed of the normal sequence of events pertaining to the performance and documentation of maintenance actions, the maintenance policies, and the options within the maintenance data reporting system available to the supporting and operating command personnel.

The measured and derived factors based on the analysis of DO56E data are listed in Tables 3-4 and 3-5 respectively. From these data files the pertinent measured values such as number of failures, flight hours, QPAs, etc. were derived and are summarized for each of the equipment/aircraft platform combinations investigated in the study. The composite results of the measured data for each of the 26 equipment/aircraft platform applications are given in Table 3-6. In addition to equipments 01 through 06, data are also included for two additional equipments (07 and 08) which were added to the data base in an attempt to gain additional insights into the characteristics of interest. Equipments 07 and 08 were the AN/APN-167 radar altimeter and air data computer respectively, and were used on the

TABLE 3-4. MEASURED FACTORS FROM DO56 DATA ANALYSIS

Symbol	Measured Factors
INV	Weapon System Inventory
FHRS	Weapon System Flight Hours
QPA	Equipment Quantity per Aircraft
K	Equipment K Factor (Operating Hours/Flight Hour)
MD	Mission Duration (Hours)
UR	Weapon System Utilization Rate (FHrs/Month/Aircraft)
MI	Maintenance Index (Maintenance Manhours/FHr.)
FTOT	Number of Total Failures
FOP	Number of Operating Failures
FNOP	Number of Nonoperating Failures
TMAS	Total Maintenance Actions
REMS	Number of Removals
NRTS	Not Repairable This Station (Return to Depot or SRA)

TABLE 3-5. FACTORS DERIVED FROM DO56 EXTRACTED VALUES

Symbol	Derived Factors
%NOP	Percentage Nonoperating Failures
MTBFTOT	MTBF in Eq. Op. Hrs. for Total Failures
MTBFOP	MTBF in Eq. Op. Hrs. for Operating Failures
MTBFNOP	MTBF in Eq. Nonoperating KHrs. for Nonoperating Failures
LAMTOT	Total Failure Rate (Lambda) (failures per million hours)
LAMOP	Operating Failure Rate (failures per million hours)
LAMNOP	Nonoperating Failure Rate (failures per million hours)
TOT/NOP	Ratio of Total to Nonoperating Failure Rates
OP/NOP	Ratio of Operating to Nonoperating Failure Rates
EUR	Equipment Utilization Rate (Eq. Op. Hrs./Month/Eq.)
%OPTIME	Percentage of Operating Time Relative to Calendar Time
F/KSRTY	Failures per Thousand Sorties
AGEHOURS	Equipment Age in Operating Hours at End of Time

F-111A, D, E, F, and FB-111A series aircraft. To facilitate the identification of the aircraft weapon system associated with each equipment type, a two-character weapon system (WS) designator is included in the first column of Tables 3-6 and 3-7 for each data entry. The first character of this designator indicates the aircraft type (i.e.: A = Attack, B = Bomber, C = Cargo, F = Fighter/Interceptor, T = Trainer). The second character of the WS designator indicates a specific aircraft MDS, such as F-15A, T-38, C-141, etc.

From the data given in Table 3-6, the composite failure characteristics (i.e.; failure rates, MTBFs, percent nonoperating failures, etc.) were derived using the methods described in paragraph 3.4.2. The results summarizing the derived equipment failure characteristics are given in Table 3-7. These two Tables (3-6 and 3-7) constitute the data base used for the analyses described in Section 4.0 of this report. Since these data represent the observed field failure characteristics (as compared with the predicted values), the terms measured MTBF, etc., will be associated with these values whenever they are referred to in subsequent sections of this report.

TABLE 3-6. ANALYSIS DATA BASE – MEASURED EQUIPMENT CHARACTERISTICS

*	WS EQ	INV	FHRS	UPA	K	MU	UN	MI	FIOT	FOP	FNOF	TMAS	REMS	NNTS
B	B9 01	336	129227	1	1.30	7.74	32.0	0.02	228	216	12	477	362	112
	CL 01	150	51351	1	1.30	4.64	28.9	0.03	135	118	17	389	179	55
	CO 01	477	254014	1	1.30	2.51	44.5	0.01	316	294	22	619	349	128
	CT 01	154	160552	2	1.30	3.41	87.4	0.01	467	433	34	803	321	182
B	BA 02	288	112217	1	1.30	7.74	32.3	0.02	314	270	44	455	239	62
	CL 02	618	215241	2	1.30	4.64	28.9	0.02	1218	1107	111	1696	746	87
	CO 02	1008	540610	1	1.30	2.51	44.5	0.02	1254	1096	158	1959	781	73
	CT 02	50	90484	2	1.30	3.41	87.4	0.01	156	118	38	202	60	22
F	TD 01	691	241747	1	1.30	1.22	29.1	0.01	268	246	22	625	521	198
	AM 01	102	44537	1	1.30	1.87	36.2	0.02	79	72	7	134	93	48
	AR 01	262	75051	1	1.30	1.63	23.7	0.05	226	212	14	452	340	113
	FV 01	251	48017	1	1.30	2.35	15.9	0.06	148	128	20	392	310	84
	TX 01	99	82851	1	1.30	1.78	70.2	0.01	95	88	7	202	116	27
F	TD 02	497	173197	1	1.30	1.22	29.1	0.02	818	711	107	1007	290	32
	FG 02	228	47594	1	1.30	1.32	17.4	0.04	178	171	7	255	171	4
	AM 02	102	44537	1	1.30	1.87	36.2	0.04	233	200	33	319	145	27
	FQ 02	80	16351	1	1.30	1.37	16.9	0.05	109	105	4	137	81	3
	AR 02	207	59832	1	1.30	1.63	23.7	0.03	194	160	34	307	156	14
	TU 02	685	251502	1	1.30	1.27	30.5	0.01	1057	990	67	1363	604	23
	TX 02	125	105188	1	1.30	1.76	70.2	0.01	296	263	33	409	204	7
B	BF 03	170	63881	1	1.18	7.66	31.3	0.26	587	489	98	959	646	98
	BJ 03	96	36465	1	1.24	7.88	31.8	0.20	322	269	53	549	356	58
B	BF 04	170	63881	4	1.16	7.66	31.3	0.04	730	475	255	974	744	98
	BJ 04	96	36465	4	1.14	7.88	31.8	0.03	319	214	105	478	362	17
F	FB 05	278	68514	1	2.21	1.33	20.5	0.09	266	194	72	913	361	37
B	CO 06	415	221668	1	1.35	2.51	44.5	0.02	677	635	42	1451	454	223
B	BA 07	66	16469	1	1.60	3.47	20.9	0.24	138	114	24	270	193	2
	FK 07	87	15241	1	1.60	2.33	14.6	0.23	129	105	24	233	167	1
F	FN 07	86	15384	1	1.60	2.35	14.8	0.41	133	102	31	258	194	3
	FY 07	89	16197	1	1.60	2.22	15.2	0.72	197	166	31	352	248	3
	FZ 07	76	16436	1	1.60	2.49	18.0	0.36	152	126	26	227	197	12
B	BA 08	66	16469	1	1.50	3.47	20.9	0.31	263	189	74	481	425	70
F	FK 08	87	15241	1	1.50	2.33	14.6	0.50	263	182	81	722	672	75
	FN 08	86	15384	1	1.50	2.35	14.8	0.18	204	173	31	307	264	81
	FY 08	89	16197	1	1.50	2.22	15.2	0.22	245	220	25	385	304	103
	FZ 08	76	16436	1	1.50	2.49	18.0	0.19	151	102	49	352	298	7[illegible]

* AIRCRAFT TYPE LEGEND: B = BOMBER/TRANSPORT, F = FIGHTER/INTERCEPTOR/TRAINER

TABLE 3-7. ANALYSIS DATA BASE — DERIVED EQUIPMENT CHARACTERISTICS

WS EQ	%NOP	MTBFTOT	MTBFOP	MTBFNOP	LAMTOT	LAMOP	LAMNOP	TOT/NOF	OF/NOF	EUR	%OPTIME	F/KSHTY	AGEHRS
B9 01	5.3	736.8	777.8	255.9	1357.2	1285.6	3.9	349.00	329.64	41.6	5.18	13.65	598
CL 01	12.6	494.5	565.7	81.0	2022.2	1767.7	12.3	164.41	143.72	37.6	4.68	12.21	163
CO 01	7.0	1045.0	1123.2	194.1	956.9	890.3	5.1	187.65	174.57	57.8	7.19	3.12	629
CT 01	7.3	893.9	966.3	75.2	1118.6	1034.8	13.2	84.74	78.39	113.6	14.14	4.96	367
BA 02	14.0	464.6	540.3	59.8	2152.3	1850.8	16.7	128.88	110.83	42.0	5.23	21.65	385
CL 02	9.1	459.5	505.5	102.2	2176.2	1978.2	9.7	224.35	203.94	37.7	4.69	13.14	594
CO 02	12.6	560.4	641.8	57.0	1784.4	1558.1	17.5	101.97	89.03	58.0	7.22	5.82	987
CT 02	24.4	841.4	1112.4	21.9	1188.4	898.9	45.6	26.06	19.71	113.7	14.15	5.27	804
TD 01	8.2	1172.7	1277.5	288.5	852.7	782.7	3.4	250.79	230.21	37.8	4.70	1.35	804
AM 01	8.9	732.9	815.5	132.7	1564.4	1226.2	7.5	181.92	165.49	47.1	5.86	3.32	598
AN 01	6.2	431.7	460.2	173.5	2316.4	2172.9	5.7	406.39	381.21	30.8	3.83	4.92	345
FV 01	15.5	421.8	487.7	117.9	2370.7	2050.4	8.4	282.25	248.10	20.7	2.58	7.24	421
TX 01	7.4	1133.7	1223.9	121.0	882.0	817.0	8.2	107.56	99.63	91.3	11.36	2.04	842
TD 02	13.1	275.3	316.7	42.7	3632.4	3157.5	23.4	155.23	134.94	37.8	4.70	5.75	444
FG 02	3.9	347.6	361.8	305.4	2876.8	2763.9	3.2	899.00	865.72	22.6	2.81	4.94	833
AM 02	14.2	248.5	289.5	28.2	4024.1	3454.2	35.4	113.68	97.58	47.1	5.86	9.79	598
FQ 02	3.7	195.0	202.4	188.4	5128.2	4940.7	5.3	967.58	932.21	22.0	2.74	9.13	746
AR 02	17.5	408.9	489.2	56.2	2494.3	2044.1	17.7	140.92	115.49	30.8	3.83	5.30	352
TU 02	6.3	309.3	330.9	93.7	3233.1	3022.0	10.6	305.01	285.09	39.6	4.93	5.33	889
TX 02	11.1	462.0	519.9	33.3	2164.5	1923.4	30.9	70.05	62.25	91.3	11.36	5.01	1476
BF 03	16.7	128.4	154.5	15.9	7788.1	6472.4	62.8	124.01	103.06	36.9	4.59	70.39	1714
BJ 03	16.5	140.4	168.1	16.5	7122.5	5948.8	60.6	117.53	98.16	39.4	4.90	69.58	1784
BF 04	34.9	406.0	624.0	24.5	2463.0	1602.5	40.8	60.37	39.28	36.3	4.52	87.54	1685
BJ 04	32.9	521.3	777.0	33.5	1918.2	1287.0	29.8	64.37	43.19	36.3	4.52	68.93	1640
FB 05	27.1	569.2	784.5	35.1	1756.8	1274.6	28.4	61.86	44.88	45.3	5.64	5.18	914
CO 06	6.2	442.0	475.8	88.1	2262.4	2101.7	11.5	200.21	185.99	60.1	7.48	7.66	465
BA 07	17.4	190.9	231.1	25.3	5238.3	4327.1	39.5	132.62	109.55	33.4	4.16	29.04	2803
FK 07	18.6	189.0	232.2	34.0	5291.0	4306.6	24.4	179.97	146.48	23.4	2.91	19.70	2272
FN 07	23.3	185.1	241.3	26.0	5402.4	4144.2	38.4	140.69	107.92	23.7	2.95	20.35	1844
FY 07	15.7	131.5	156.1	26.7	7604.5	6406.1	37.4	203.33	171.29	24.3	3.02	26.98	2897
FZ 07	17.1	173.0	208.7	27.2	5780.3	4791.5	36.7	157.50	130.56	28.8	3.58	23.05	2639
BA 08	28.1	93.9	130.7	8.2	10649.6	7651.1	121.9	87.36	62.77	31.3	3.90	55.35	2628
FK 08	30.8	86.9	125.6	10.1	11507.4	7961.7	99.0	116.24	80.42	21.9	2.75	40.16	2130
FN 08	15.2	113.1	133.4	26.1	8841.7	7496.2	38.3	230.85	195.72	22.2	2.76	31.21	1729
FY 08	10.2	99.2	110.4	33.2	10080.6	9057.9	30.1	334.90	300.95	22.8	2.84	33.56	2716
FZ 08	32.5	163.3	241.7	14.5	6123.6	4137.3	68.9	88.88	60.05	27.0	3.36	22.90	2474

4.0 ANALYSIS

Several different approaches were used to perform analysis tasks to develop the failure rate data for the six equipments included in the study as shown in Figure 4-1.

The first approach was to develop predicted operating and non-operating failure rates using the methods and data given in MIL-HDBK-217B, and two other nonoperating failure rate prediction methods developed by RADC and MIRADCOM.

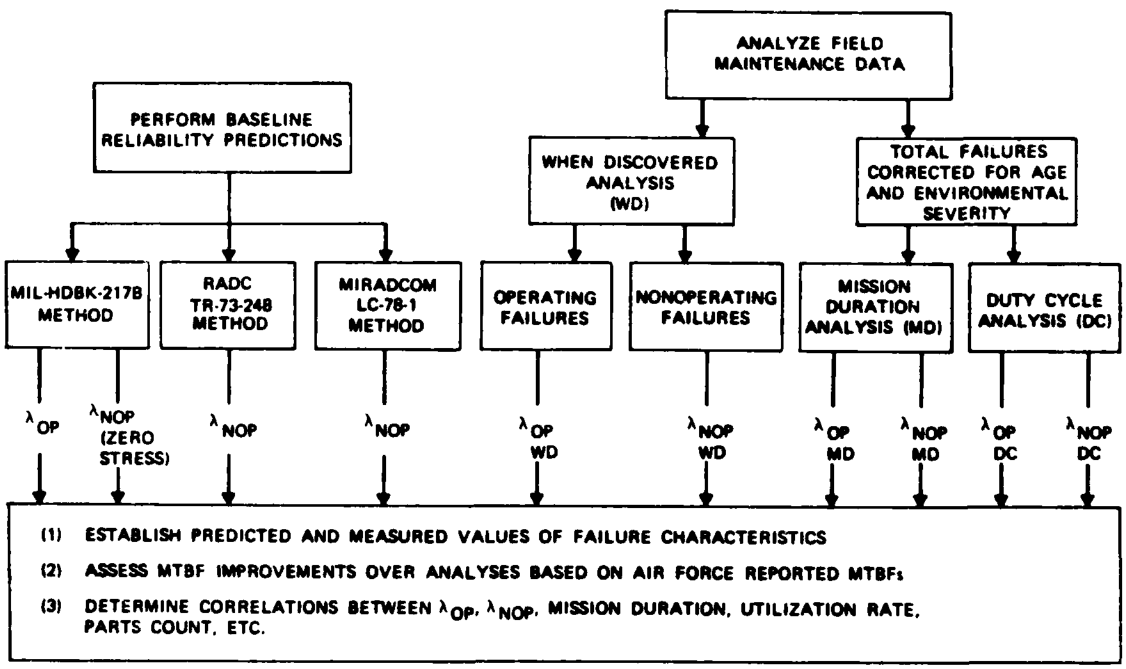

Figure 4-1. Analysis Task Diagram

The second approach developed the same two parameters using field maintenance data and performing analyses based upon classification of failures into operating or nonoperating failure categories using the When Discovered (WD) codes. From these data, the measured field failure rates (λ_{OP}, λ_{NOP}) for each of the 26 different applications of the six equipment types of interest were derived. A review of the data indicated that three of the 26 applications on which the data were computed had insufficient experience to permit inclusion in the analysis. These were applications which had an average inventory of 100 or less operational equipments during the time period of interest. The applications excluded for this reason were the ARN-118 TACANs on the T-39 aircraft and the ARC-164 UHF radios on the C-141 and F-101 aircraft. Unless otherwise specified all subsequent discussions and analyses, are based on the resultant (censored) data set of 23 applications. From these values, average operating and nonoperating failure rate values for each of the six equipment types were developed for comparison with the predicted failure rate values discussed previously.

The third approach to estimation of nonoperating failure rates was based on two different types of regression analysis models in which the field data characterizing the total failure rates were analysed in such a way that the contribution of nonoperating failure rates could be assessed using the models. These regression models used mission duration (MD) and duty cycle (DC) as the independent variables from which the desired failure rates were derived.

The methods used for each of the analysis tasks and results obtained are described in this section. A summary of the analysis results and inferences to be drawn are included in Section 5.0 of this report.

4.1 RELIABILITY PREDICTIONS

4.1.1 Equipment Reliability Prediction Assessments

The detailed reliability prediction reports for each of the six equipments included in the study were obtained from the original equipment manufacturers for review and analysis. A review of the prediction reports revealed that the equipment manufacturers used a variety of government sources for failure rates, ranging from MIL-HDBK-217A to MIL-HDBK-217B, and/or their own internal failure data sources. Furthermore, each manufacturer tended to apply his own ground rules when making predictions. Because these prediction analyses were prepared under a variety of ground rules and requirements, it was necessary to prepare a new reliability prediction assessment for each of the six equipments so that a common reliability prediction baseline in accordance with MIL-HDBK-217B could be established in support of the study analysis tasks.

The predicted operational reliability of each of the equipments included in the study was reassessed using the methods in MIL-HDBK-217B and other appropriate data for those items not included in MIL-HDBK-217B. This task was performed at the equipment and LRU levels using a computerized reliability prediction program based on MIL-HDBK-217B developed by Hughes known as ASRAP (Assumed Stress Reliability Analysis Program).

The ASRAP series of programs provide for rapid calculations of system failure rate and MTBF within a specified use environment under varying conditions of temperatures, stress, and part quality. The computer program includes complex failure rate equations for each part type. The elements of each equation consist of a base failure rate (λ_b) predicted on thermal and electrical stress and a series of adjustment factors to account for the use environment, quality level, design ratings, etc. As an illustration, consider the failure rate equation for a transistor:

$$\lambda_p = (\lambda_b)(\pi_E)(\pi_A)(\pi_Q)(\pi_R)(\pi_{S2})(\pi_C)$$

where:

λ_p = Total part failure rate

λ_b = Base failure rate

π_E = Environmental use factor

π_A = Application factor

π_Q = Quality factor

π_R = Power rating factor

π_{S2} = Voltage stress factor

π_C = Complexity factor.

This detailed approach to part failure rate determination is typical of the equations used in failure rate sources such as MIL-HDBK-217B, which are included in the ASRAP program.

The use of the ASRAP program provided the required baseline predictions for each of the NOFRA study equipments in accordance with MIL-HDBK-217B, thereby assuring a uniform prediction baseline for each of the six equipments included in the study.

4.1.2 Ground Rules and Assumptions

It was necessary to establish a standard set of ground rules and assumptions where MIL-HDBK-217B did not include failure rates for certain parts included in this study. These criteria were applied to all of the selected equipments and used to establish the common baseline predictions:

1. In several instances (capacitors and high stress ratio diodes), values for certain parameters (stress ratio versus temperature) were of a magnitude not available from the curves. The RADC Notebook (Reference 38) was used in these cases.
2. Equipment manufacturer failure rates were utilized in those few instances where a device was considered proprietary by a manufacturer and no information was available.
3. The application factor for Group I and II transistors was assumed to be linear unless the device was used as a logic switch.

4. The voltage stress for Group I Transistors was established at 60 percent, because precise stress values were not available.
5. Insert material for connectors was assumed to be Type A unless otherwise stated or known (coax).
6. Voltage stress ratios for Group IV diodes were defined as 100 percent.
7. Unless otherwise known, filter configurations were assumed to be Pi.
8. An application factor of 2.0 was assigned to "CY" capacitors having a capacitance greater than 10,000 pFd.
9. Hybrid thin film equations were used to determine failure rates of resistor networks.

4.1.3 Predicted MTBF Assessment Results

The ASRAP program was run to derive the predicted MTBF values for each of the six equipments under its nominal operating conditions, and then run again for different levels of stress, temperature, and environment representing the nonoperating condition for each equipment.

Although MIL-HDBK-217B explicitly cautions against the extrapolation of the failure rate models for components to the zero stress level, an estimate was made of the nonoperating MTFB using this method so that a first order prediction might be obtained for informational purposes. This was done using the environmental use factor for Ground Fixed equipment at the zero stress level and at a temperature of 30°C which was judged to be the best approximation to the avionic equipment's nonoperating environment.

A summary of the results of these analyses and the values for the original MTBF predictions performed by the equipment manufacturers for each of the six equipments included in the study is given in Table 4-1. It is evident that the results of the zero stress level analysis are unrealistically high by at least an order of magnitude, when compared to the known field experience. In part, this may be due to the influence of the fixed special part failure rates used for items not included in MIL-HDBK-217B, which do not change as a function of stress or environment.

TABLE 4-1. REPREDICTED MTBF ASSESSMENT RESULTS

Equipment Number	Equipment Manufacturer's Predicted MTBF	Hughes Predicted* Baseline MTBF $(\lambda_{OP})^{-1}$	Predicted* Nonoperating MTBF$(\lambda_{NOP})^{-1}$	Ratio* $\lambda_{OP}/\lambda_{NOP}$
01	1,092	1,205	3,406	2.83
02	3,075	3,457	7,623	2.21
03	142	236	1,349	5.72
04	1,014	2,633	3,915	1.49
05	1,437	2,732	9,411	3.44
06	1,118	1,274	1,944	1.53

*Based on MIL-HDBK-217B.

Also included in Table 4-1 is the ratio of each equipment's predicted operating to nonoperating failure rate for subsequent comparison with the measured ratio of the same parameters based on field maintenance data analysis.

By examining the results obtained, it is clear that the relatively low ratios of operating to nonoperating failure rates do not seem reasonable. Other variables to consider are the inconsistencies in the criteria used for the determination of relative parts count and complexity factors, and/or the inclusion of special part failure rates for those parts not included in MIL-HDBK-217B.

After a careful review of the details of each zero stress prediction analysis, it was observed that a considerable part of the nonoperating failure rates were attributable to special components for which no failure rate models exist in MIL-HDBK-217B; hence, these parts limited the degree of failure rate reduction possible at the nonoperating (zero stress) level.

To examine this point in more detail, an assessment of the contribution of non-217B parts was prepared for each of the six equipments studied.

The effect of the non-217B parts was assessed in terms of relative parts quantity and also the percentage of the total failure rate for comparison with the predicted ratios of operating to nonoperating failure rates. The impact of these non-standard parts on the resultant nonoperating failure rate predictions is given in Table 4-2. It is evident that in the case of equipments 03 through 06, the non-217B parts failure rate contribution to the total nonoperating failure rates completely dominates the resultant predicted values.

TABLE 4-2. PARTS FAILURE RATE SUMMARY

Equipment Number	Percent Non-217B Parts Count	Percent λNOP Contribution		Ratio λOP/λNOP
		Std-217B	Non-217B	
01	1.9	88.4	11.6	2.83
02	2.8	84.8	15.2	2.21
03	2.7	38.9	61.1	5.72
04	2.3	32.9	67.1	1.49
05	0.9	40.9	59.1	3.44
06	6.8	42.9	57.1	1.53

Alternatively, if one were to establish a judgmental factor with which to treat the non-217B parts failure rates in the absence of actual data, the results would most likely be equally suspect. For these reasons, and the previously stated disclaimer in MIL-HDBK-217B regarding predictions based on extrapolation to the zero stress levels, these predicted nonoperating failure rates must be viewed with caution.

4.1.4 Predicted Nonoperating Failure Rates

Two additional methods for predicting nonoperating failure rates from available data were investigated. These were based on prediction methods described in RADC-TR-73-248 and U.S. Army MIRADCOM Report LC-78-1 (References 34 and 36, respectively). The first method, which was developed by Martin-Marietta under contract to RADC is described in the report "Dormancy and Power On-Off Cycling Effects on Electronic Equipment and Parts" dated August 1973. It is important to note that the dormant failure rates contained in this report have the following characteristics:

1. The dormant failure rate for microelectronic devices did not account for complexity of the devices.
2. In general, the report only provides dormant failure rates for various component groups. As an example, for MIL-STD capacitors, only three groups of dormant failure rates were provided.

The second prediction method was based on component nonoperating failure rates listed in the U.S. Army Missile Research and Development Command's Report LC-78-1, entitled "Missile Material Reliability Prediction Handbook - Parts Count Prediction," dated February 1978. This report provides more detailed nonoperating failure rate information. For example, for MIL-STD capacitors, the best estimated nonoperating failure rates of 21 different type capacitors were provided. In addition to the best estimate nonoperating failure rate of each type, a 90 percent upper confidence limit was also presented. For the second set of predictions the best estimated value of each nonoperating failure rate was used. To facilitate subsequent reference to these two methods, they will be referred to as the RADC method and MIRADCOM method, respectively.

A review of the six individual prediction analyses indicated that the dominant contributors to the nonoperating failure rate characteristics of the equipments did not follow any consistent pattern. In some cases the principal contributors were low population devices such as switches, thermal resistors, connector panels, filters, lamps, etc., whereas in other case they were the high population devices such as resistors, capacitors, ICs, etc., or some combination of the two categories indicated.

The results of these two methods yielded the values given in Table 4-3 of nonoperating failure rates for each of the six equipments included in the study. To facilitate comparisons, the average measured nonoperating failure rates derived from the data in Table 3-7 have also been included in Table 4-3. Measured average nonoperating failure rates were derived from the individual equipment values given in the column labelled LAMNOP of Table 3-7 (page 3-30).

TABLE 4-3. PREDICTED AND MEASURED NONOPERATING FAILURE RATES (IN FAILURES PER MILLION HOURS)

Equipment Number	Predicted Nonoperating Failure Rates		Measured Nonoperating Failure Rates
	per RADC-TR-73-248	per MIRADCOM LC-78-1	
01	86.1	29.2	7.4
02	61.8	35.7	18.3
03	589.7	118.8	61.7
04	26.6	10.3	35.3
05	101.0	37.3	28.4
06	99.2	31.9	11.3

Note that in the case of equipments 01 and 02 the average measured nonoperating failure rates are based on the censored data set on which the final analysis results were based. The equipment applications censored were those having an annual average of 100 or less installed equipments. The difference in the measured values of nonoperating failure rates with or without censoring is negligible (i.e.: 7.5 and 19.7 for equipments 01 and 02 respectively). Since comparisons are subsequently made between results obtained using different analysis methods, all analysis results given in this report are based on the censored data set to maintain a consistent basis of comparison.

4.1.5 Comparison of Predicted and Measured Nonoperating Failure Rates

To provide a comparison of the results of the three different non-operating failure rate prediction methods used, the ratios of the predicted to measured nonoperating failure rates were calculated. This was done for each of the six equipments based on the average failure rate values for each equipment based on the measured nonoperating failure rates given in Table 3-7 in the column headed LAMNOP. The results are presented in Table 4-4.

TABLE 4-4. PREDICTED TO MEASURED λ_{NOP} RATIOS

Equipment Number	Predicted to Measured λ_{NOP} Ratio		
	MIL-HDBK-217B Zero Stress	RADC TR-73-248	MIRADCOM LC-78-1
01	39.2	11.5	2.8
02	6.6	3.1	1.2
03	12.0	9.6	0.9
04	7.2	0.8	0.3
05	18.1	3.6	1.2
06	9.4	8.8	2.7

Although the comparison indicates that the MIRADCOM prediction method gave the best results, an examination of the ratios for each of the six equipments using this method indicates an unacceptably large variation among the six equipment items. Because of concern over the reasons for the variation, a subsequent investigation of other possible causal factors related to the maintenance data is included in Section 4.6 of this report.

A subsequent set of regression analyses was performed to evaluate the three methods of nonoperating failure rate prediction; the results are presented in Section 4.4.2 through 4.4.5 of this report.

4.2 COMPOSITE FIELD PERFORMANCE ASSESSMENTS

This section of the report deals with the analyses performed to derive the desired field performance characteristics of the 26 equipment/aircraft applications included in the study and the composite average values of the parameters of interest for each of the six equipment types. The composite parameters evaluated consisted of the failure rate characteristics, the improvement factors resulting from the elimination of nonoperating failures from operational MTBF assessments, and the environmental severity factors and age factors required for subsequent regression analysis tasks.

4.2.1 Composite MTBF Assessments

The composite values of the measured MTBF characteristics for each of the six equipment types were calculated using the failure rate data for the three indices of interest (total, operating and nonoperating failure rate) listed in the columns headed LAMTOT, LAMOP, and LAMNOP respectively listed in Table 3-7.

The composite MTBF values were then derived using the expression

$$Composite\ MTBF = (\bar{\lambda})^{-1}$$

where

$$\bar{\lambda}_{TOT} = \frac{\sum_{1}^{n} \lambda_{TOT}}{n}$$

and in a similar manner, the values of the operating and nonoperating failure rates were obtained.

The results of these calculations for the six equipments and the predicted values derived in the preceding section were then reviewed and compared and figures of merit comparing the predicted MTBFs to the measured MTBFs were calculated. The results are given in Table 4-5. Note that one additional factor has been included for comparison purposes, labelled Measured Inherent MTBF. This factor is an independently derived value of measured MTBF resulting from independent contractor assessments performed under RIW (Reliability Improvement Warranty) contracts on Equipment 01 and 06.

These indices (inherent MTBF) use assessment criteria that are more consistent with the criteria used for predictions of MTBF per MIL-HDBK-217B. As can be seen, the figures of merit, ratio of predicted MTBF to inherent MTBF are considerably improved over those based on assessments using field maintenance data and HQ AFLC assessment criteria.

Table 4-5. Composite MTBF Assessment Data

Eq. No.	Baseline Predicted MTBF	Measured Total MTBF*	Measured Operating MTBF*	Measured Inherent MTBF	Predicted/Field MTBF Discrepancy Factor		
					P/TOT	P/OP	P/INH
01	1205	679.7	748.3	2024	1.73	1.61	0.59
02	3457	356.5	398.7	N/A	9.70	8.67	N/A
03	236	134.1	161.0	N/A	1.76	1.47	N/A
04	2633	456.5	692.1	N/A	5.77	3.80	N/A
05	2732	569.2	784.5	N/A	4.80	3.48	N/A
06	1274	442.0	475.8	880	2.88	2.68	1.45

*Based on Average of Failure Rates

4.2.2 Composite Failure Rate Assessments

The composite values of the measured failure characteristics for each of the six equipments were calculated using failure data for the three indices of interest (total failures, operating failures, and nonoperating failures) listed in the columns headed FTOT, FOP, and FNOP respectively in Table 3-7. An additional factor of interest, the ratio of the composite operating to nonoperating failure rates, which is used in subsequent analysis tasks was also calculated and is included in Table 4-6. Note that in each case the values given for equipments 01 and 02 represent the censored data set for each of the indicated parameters. This was done to facilitate the comparisons made in the subsequent analyses, which are based on the censored data set as explained in the section that follows.

TABLE 4-6. COMPOSITE FAILURE CHARACTERISTICS DATA

Eq. No.	Average Number of Failures			Average Failure Rate*			$\overline{\lambda}OP / \overline{\lambda}NOP$ Ratio
	FTOT	FOP	FNOP	$\overline{\lambda}TOT$	$\overline{\lambda}OP$	$\overline{\lambda}NOP$	
01	233.4	214.9	18.5	1545	1401	7.4	188.4
02	618.0	552.0	66.0	2726	2417	18.3	131.8
03	454.5	379.0	77.5	7547	6211	61.7	100.7
04	524.5	344.5	180.0	2191	1445	35.3	40.9
05	266.0	194.0	72.0	1757	1275	28.4	44.9
06	677.0	635.0	42.0	2262	2102	11.3	186.0

*Failure Rate is in failures per million hours (F/mh).

4.2.3 Environmental Severity Factor Calculations

To provide a means for combining the data representing a given equipment type used on both bomber transport and fighter interceptor type aircraft, a means of normalizing the failure data to a common environmental severity factor was required. This was done by defining the environmental severity factor as the ratio of the average failure rate on fighter intercepter applications to the average on bomber/transport applications for the ARN-118 TACAN and the ARC-164 UHF Radio. These factors were calculated and the resultant values derived as follows:

$$\text{Eq. 01 ESF} = \frac{\overline{\lambda}TOTF01}{\overline{\lambda}TOTB01} = \frac{1726.05}{1363.73} = 1.2657$$

$$\text{Eq. 02 ESF} = \frac{\overline{\lambda}TOTF02}{\overline{\lambda}TOTB02} = \frac{3070.87}{2037.63} = 1.5071$$

4.2.4 Average Age Factor Calculations

Since the equipments selected for special studies were of different population age characteristics on the various aircraft applications, a means of establishing the age factor (i.e.; the ratio of the equipment's average age on a given aircraft type to the average age of all applications using the same equipment) was devised. This was accomplished by reviewing the installation data for each equipment application of interest and compiling the annual average age values from the installation data provided by AFLC. The method of calculation was as follows:

$$\text{Annual Average Age} = \frac{\sum_{1}^{n} \text{AGEHRS}}{n}$$

where n = number of aircraft type applications.

Based on the data from Table 3-7, Column AGEHRS, the average age factor values for equipments 01 and 02 were calculated as follows:

$$\text{Eq. 01 Average} = \frac{3925}{8} = 490.63$$

$$\text{Eq. 02 Average} = \frac{6518}{9} = 724.22$$

4.3 NONOPERATING FAILURE IMPACT

4.3.1 Measured Nonoperating Failure Rate Assessment

The nonoperating failure rates were assessed for each of the 26 equipment/aircraft applications included in the study and ratios of the operating to nonoperating failure rates plotted on a nomograph to provide a graphical presentation of how this characteristic varies with the equipment utilization rate.

In addition, several plots were prepared to present a graphical picture of the distribution of nonoperating failures in terms of population distribution, improvement factor distributions, and the distribution within each equipment type. These plots appear in Figures 4-2 through 4-5 respectively.

Examining the data points of Figure 4-2, it appears that there is considerably more scatter to the data than what one would expect if the failure rate ratio ($\lambda OP/\lambda NOP$) for a given equipment was primarily an intrinsic characteristic of the equipment. This suggests that perhaps other factors are influencing the data used for the assessment, thereby causing the wide range of variations observed. Since the study was limited to the use of available data, this phenomenon could not be investigated further; however there are several possible causes that appear to be responsible, based on detailed inquires and discussions held with field maintence and logistics specialists on this subject. These are discussed separately in Section 4.6 of this report along with several related observations on the use of field maintenance data for reliability assessment purposes.

4.3.2 Impact of Nonoperating Failures on MTBF Assessment

The degree to which the assessed operational MTBF is improved by excluding nonoperating failures from the total failures counted was evaluated for each of the 26 equipment/aircraft applications and also for the composite value of each of the six equipment types. The calculation method utilized was as follows:

$$\text{Improvement Factor} = \frac{MTBF_{OP}}{MTBF_{TOT}} = \frac{\lambda_{TOT}}{\lambda_{OP}}$$

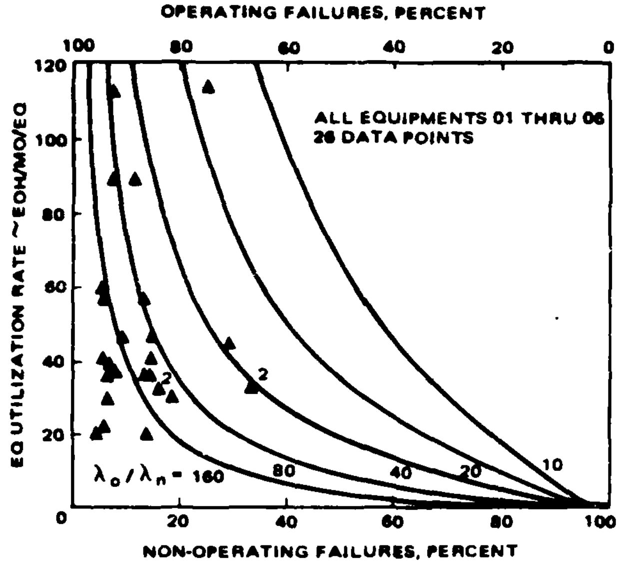

Figure 4-2. Ratio of operating to nonoperating failures.

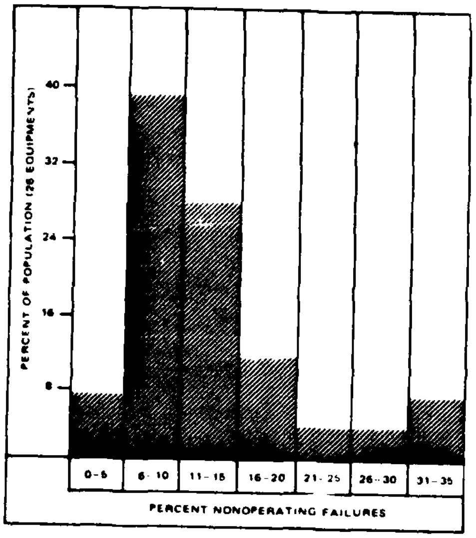

Figure 4-3. Nonoperating Failure Percentage Distribution (26 Equipment Sample)

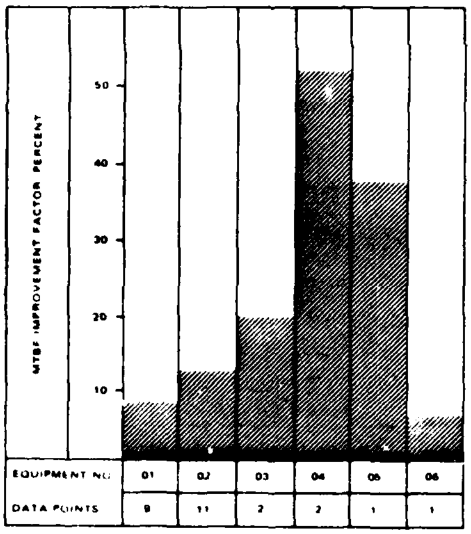

Figure 4-4. Percentage MTBF Improvement Factors (6 Equipment)

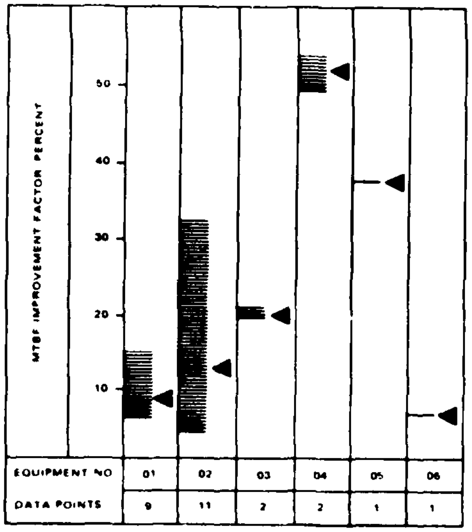

Figure 4-5. Percentage MTBF Improvement Factors (26 Data Points, 6 Equipments)

$$\text{Composite Improvement Factor} = \frac{\bar{\lambda}_{TOT}}{\bar{\lambda}_{OP}}$$

using the data for the items of interest given in Table 3-7 in the columns headed LAMTOT and LAMOP for the values of the respective total and operating failure rates.

The results of the calculation of the improvement factors and the related average values are given in **Table 4-7** and are plotted in Figures 4-3 through 4-5. Figure 4-3 is a plot in which the values of each of the applications' 26 improvement factors have been ordered in 5% increments so that a population distribution of the improvement factors (expressed in percentile increments) is obtained.

Table 4-7. Composite MTBF Improvement Factors Data

Eq. No.	Nonoperating Failure Rate (F/mh)	$\lambda_{OP}/\lambda_{NOP}$ Ratio	Percent Nonoperating Failures	Avg. MTBF Improvement Factor	Min. MTBF Improvement Factor	Max. MTBF Improvement Factor
01	7.4	188.4	7.9	1.086	1.056	1.144
02	18.3	131.8	10.8	1.120	1.038	1.322
03	61.7	100.7	16.6	1.199	1.197	1.203
04	35.3	40.9	34.3	1.522	1.490	1.537
05	28.4	44.9	27.1	1.371	1.371	1.371
06	11.3	186.0	6.2	1.066	1.066	1.066
Avg.	---	---	17.2	1.277	---	---

Figure 4-4 indicates the composite results for each equipment and shows a range of improvement factors varying almost 10 to 1 among the six composite values. Figure 4-5 also includes an additional factor of interest, namely the range over which this factor varies within a given equipment. As can be seen, Equipment 02 (UHF Radio) which is represented by 11 different applications has an improvement factor of 1.038 on the low end of its range to 1.322 on the high end.

4.4 GENERAL REGRESSION ANALYSIS

Multiple regression analysis is a useful statistical technique to account for the functional relationship between factors or variables under study. This can be accomplished by considering the joint variation of the variables from empirical or experimental data.

In a multiple regression analysis, for example, the degree of correlation between random variables can be measured by the coefficient of correlation (or its square – index of determination) which has possible a range of values from 0 to ±1. A correlation between one or more random variables is nonexistent when the coefficient of correlation is zero and there is perfect correlation when the coefficient of correlation is 1; the regression equation provides a means for predicting the best estimate of a dependent variable when the values of the independent variables are given.

For this analysis, a computer program based on a stepwise regression analysis procedure was used. The program computes a sequence of multiple linear regression equations in a stepwise manner. At each step, one variable is added to the regression equation. The variable added is the one that makes the greatest reduction in the error sum of squares. It is the variable that has the highest partial correlation with the dependent variable (operating or nonoperating failure rates); i.e., this variable has the most significant effect on the dependent variable. On the other hand, the less significant variables will be automatically removed in accordanoe with a given level of significance.

A multiple regression analysis was performed using the following factors:

1. Nonoperating MTBF as dependent variable
2. Percent nonoperating failures
3. Ratio of operating to nonoperating failure rate
4. Maintenance index (MI)
5. Equipment utilization rate
6. Percent operating time
7. Failures per sortie
8. Mission duration

9. Total maintenance actions
10. Removals per equipment
11. Removals per flight hour
12. Failures per equipment per year
13. Average equipment age in operating hours
14. Flight hours per equipment.

Six sets of data representing selected combinations of equipments 01 and 02 and aircraft application were analyzed and are listed in Table 4-8.

TABLE 4-8. MULTIPLE REGRESSION ANALYSIS DATA SETS

Set	Equipment/Application	Data Points in Sets
I.	Equipment No. 01 Bomber/Transport	4 points
II.	Equipment No. 02 Bomber/Transport	4 points
III.	Equipment No. 01 Fighter/Interceptor	5 points
IV.	Equipment No. 02 Fighter/Interceptor	7 points
V.	I and III Combined	9 points
VI.	II and IV Combined	11 points

The analyses were concentrated on equipments 01 and 02 because these two equipment types provided the largest number of data points and would most likely provide useful results for the development of predictive models. The remaining four equipments (03 through 06 respectively) could not be used for model development since each of these equipment types were only operational on one or two aircraft applications.

The general regression analysis results indicated that two of the factors, namely mission duration and percent operating time appeared to be significant in influencing field failure rates. This confirms simular findings in a previous study (Reference 6) on operational influences on avionic equipment reliability. The correlation coefficents of these two factors relative to measured failure characteristics (i.e.: failures per sortie and failures per equipment per year) are given in Table 4-9. Note that the correlation coefficients of both factors for four of the six data sets evaluated are greater than 0.8.

TABLE 4-9. SUMMARY OF CORRELATION COEFFICIENTS OF IMPORTANT FACTORS

Dependent Variables	Independent Variables											
	Mission Duration						Percent Operating Time					
	Sets						Sets					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
Failures/ Sortie	0.888	0.859	0.806	0.325	0.892	0.884						
Failures/ Equipment							0.885	0.834	0.597	0.801	0.792	0.515
No. of data pts	4	4	5	7	9	11	4	4	5	7	9	11

Specially selected analyses based on these factors for data sets V and VI are described in Section 4.5. Although the coefficients of correlation for these two sets were not the highest shown in Table 4-9, these sets were selected for analysis because 1) they have the largest number of data points (9 and 11, respectively) and 2) with normalization for age and environment they provided the best overall results as indicated by both the index of determination and the consistence with observed trends.

4.4.1 Evaluation of Failure Rate Predictors

In Sections 4.4.2 through 4.4.8 the measured failure rates based on the 26 data points for the six equipment types and the ratios of failure rates are compared to:

1. Failure rate predictions based on MIL-HDBK-217B
2. Nonoperating failure rate predictions based on the RADC method
3. Nonoperating failure rate predictions based on the MIRADCOM method
4. The total number of electronic parts
5. The number of microelectronic parts (ICs and Hybrids), and
6. The ratio of microelectronic parts to total electronic parts.

The data used for these analyses are listed in Table 4-10 from which the following 16 sets of simple regression analyses were performed:

1. Measured λ_{OP} versus predicted λ_{OP} (MIL-HDBK-217B method)
2. Measured λ_{NOP} versus predicted λ_{NOP} (217B zero stress method)
3. Measured λ_{NOP} versus predicted λ_{NOP} (RADC method)
4. Measured λ_{NOP} versus predicted λ_{NOP} (MIRADCOM method)
5. Measured λ_{OP} versus number of microelectronic parts
6. Measured λ_{NOP} versus number of microelectronic parts
7. Measured λ_{OP} versus total number of electronic parts
8. Measured λ_{NOP} versus total number of electronic parts
9. Measured λ_{OP} versus ratio of microelectronic to total electronic parts
10. Measured λ_{NOP} versus ratio of microelectronic to total electronic parts
11. Ratio of measured λ_{OP} to λ_{NOP} versus number of microelectronic parts
12. Ratio of measured λ_{OP} to λ_{NOP} versus total electronic parts
13. Ratio of measured λ_{OP} to λ_{NOP} versus ratio of microelectronic total electronic parts
14. Ratio of λ_{OP} to λ_{NOP} versus measured λ_{OP}
15. Ratio of measured λ_{OP} to λ_{NOP} versus measured λ_{NOP}
16. Ratio of measured λ_{OP} to λ_{NOP} versus ratio of predicted λ_{OP} to λ_{NOP}.

TABLE 4-10. EQUIPMENT FIELD FAILURE RATE AND PARTS MIX DATA

Equipment Number	Field Measured Values			Number of Micro-electronic Parts	Total Number of Electronic Parts	Micro-electronic Parts, Percent
	$\overline{\lambda}_{OP}$	$\overline{\lambda}_{NOP}$	$\frac{\overline{\lambda}_{OP}}{\overline{\lambda}_{NOP}}$			
01	1336	7.5	177.7	456	2870	16.4
02	2508	19.7	127.7	77	1636	4.7
03	6211	61.7	100.7	486	8071	6.0
04	1445	35.3	40.9	6	481	1.2
05	1275	28.4	44.9	1356	3760	36.1
06	2102	11.3	186.0	201	932	21.6

The method of analysis used was a least squares fit program called CURVFIT. The CURVFIT program is designed to compare plotted data points on X-Y axes with various algebraic and exponential functions using a least squares fit to determine a curve and mathematical expression for that curve which best fits the plotted points. In addition, the CURVFIT program calculates the index of determination (coefficient of correlation squared) for each of the six standard curves against which the input data are fitted. The output of the analysis resulting from each data set analyzed is displayed in tabular form indicating the index of determination and values of the constants A and B for each of the six standard equations. This program was used to evaluate the relationships discussed in the remainder of this section. An example of the output format, from which the best curve fitted is selected is included in the discussion of the first set evaluated, namely the relationship between the predicted and measured operating failure rates of the six equipments studied.

Of the 16 regression analyses performed, only seven were found to be statistically significant or of special interest. These seven detailed analyses are described in paragraphs 4.4.2 through 4.4.8 of this section.

4.4.2 Predicted versus Measured Operating Failure Rates Based on MIL-HDBK-217B

The regression analysis result shows that the index of determination between predicted and measured operating failure rates is 0.92.

The regression equation is:

$$Y = -775.6 + 0.777(X)$$

where:

X = measured operating failure rate

Y = predicted operating failure rate.

The regression equation is plotted in Figure 4-6.

The results suggest that there is a reasonably good correlation between the predicted and measured operating failure rates. However, the regression line, which is plotted in Figure 4-6, is wholly controlled by Equipment 03.

Table 4-11. Regression Analysis Results - MIL-HDBK-217B
Predicted versus Measured Operating Failure Rates

LEAST SQUARES CURVES FIT			
CURVE TYPE	INDEX OF DETERMINATION	A	B
1. Y=A+(B*X)	.915238	-775.567	.777079
2. Y=A*EXP(B*X)	.734248	228.526	4.48322E-04
3. Y=A*(X^B)	.628781	2.83908E-02	1.3222
4. Y=A+(B/X)	.606411	3884.35	-5.06666E+06
5. Y=1/(A+B*X)	.38651	2.91004E-03	-3.98728E-07
6. Y=X/(A+B*X)	.22056	2.41268	6.20031E-04

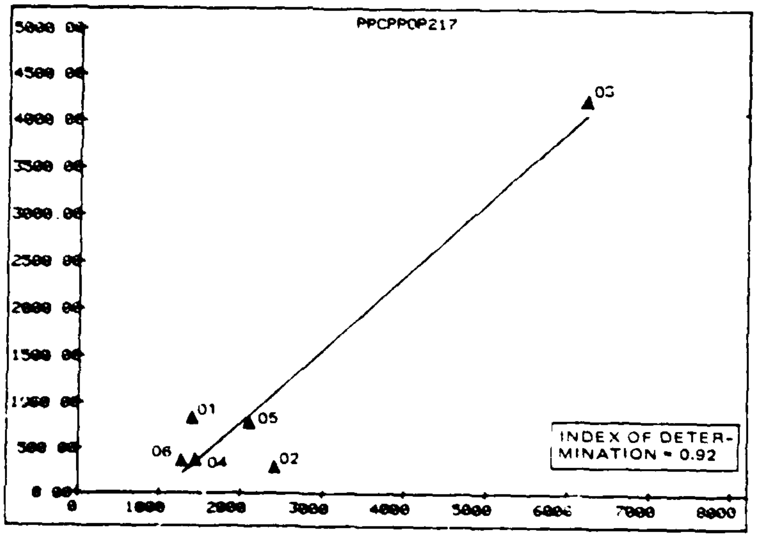

Figure 4-6. Predicted versus measured operating failure rates (MIL-HDBK-217B method).

Without the Equipment 03 point the best-fit curve would show an inverse relationship between the measured and predicted failure rates. This indicates that the unpredictable factors are so large that for the group of equipments without Equipment 03, the variation in equipment complexity is not sufficient for performing a correlation analysis of predicted versus measured failure rates. Alternatively, it is also apparent from a review of the measured failure rates that the maintenance data records from which the measured failure rates are derived are subject to considerable variation because of factors such as differences in maintenance and documention practices, data quality, etc.

4.4.3 Predicted versus Measured Nonoperating Failure Rates Based on MIL-HDBK-217B

Through the simple regression analysis, the index of determination between predicted and measured nonoperating failure rate is 0.28.

The regression equation is:

$$Y = 164.4 + 6.503(X)$$

Where:

X = measured nonoperating failure rate

Y = predicted nonoperating failure rate.

The regression equation is plotted as shown in Figure 4-7.

The predicted nonoperating failure rates were based on the parts zero stress failure rates from MIL-HDBK-217B. It is realized that the handbook rates are not to be used for calculating nonoperating failure rates. They were calculated for the purpose of examining possible correlations only. A closer examination revealed that a rather large part of the failure rates was attributed to parts for which no failure rate models exist in MIL-HDBK-217B. These parts failure rates remained the same for both operating and nonoperating conditions and in effect dominated the nonoperating failure rates of the equipments. Therefore, the predicted nonoperating failure rates should not be considered representative of MIL-HDBK-217B zero stress rates.

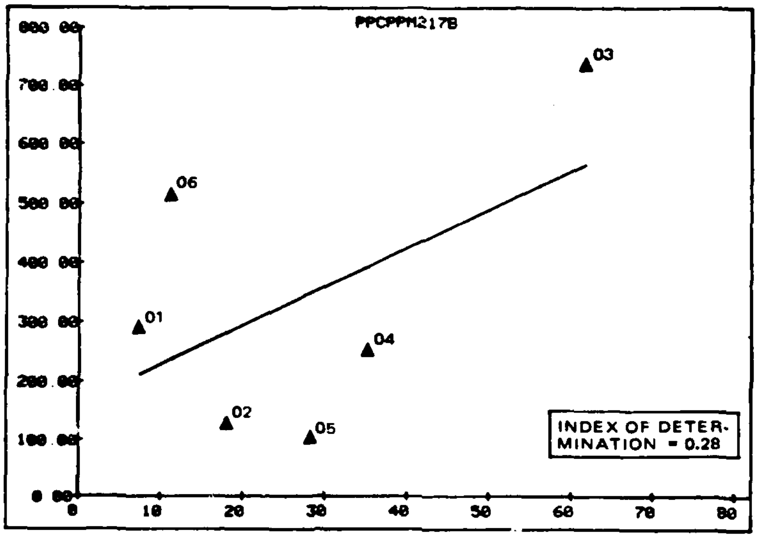

Figure 4-7. Predicted versus measured nonoperating failure rates (MIL-HDBK-217B method).

4.4.4 Predicted versus Measured Nonoperating Failure Rates Based on RADC Method

Through regression analysis, the following results were determined for predicted versus measured nonoperating failure rates based on the prediction analysis results using the method given in RADC-TR-73-248.

The index of determination between the predicted and measured nonoperating failure rates is 0.65.

The regression equation is:

$$Y = -71.2 + 8.569(X)$$

where:

X = measured nonoperating failure rate

Y = predicted nonoperating failure rate (based on RADC method).

The regression equation and corresponding data points are plotted in Figure 4-8. However, it should be noted that the equation is heavily dependent on the data point representing equipment 03. Therefore, although the results appear to be statistically significant, caution should be taken when using this equation, which, if omitted would result in a negative relationship between measured versus predicted nonoperating failure rates.

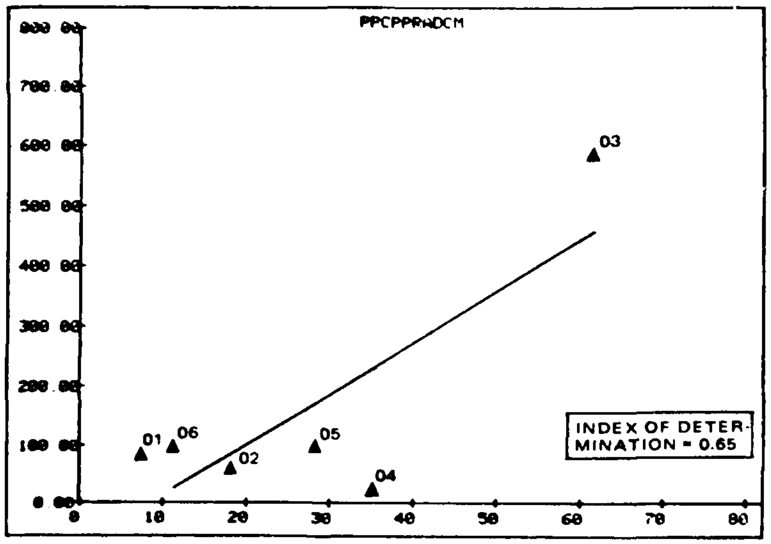

Figure 4-8. Predicted versus measured nonoperating failure rates (RADC method).

4.4.5 Predicted versus Measured Nonoperating Failure Rates Based on MIRADCOM Method

Following the same approach to analysis of the data (Table 4-2) resulting from the nonoperating failure rate predictions using the MIRADCOM LC-78-1 method (Raytheon report), the following regression analysis results were obtained.

The index of determination between the predicted and measured nonoperating failure rates is 0.57.

The regression equation is:

$$Y = 4.8 + 1.443(X)$$

where:

X = measured nonoperating failure rate

Y = predicted nonoperating failure rate (based on MIRADCOM method)

The regression equation and corresponding data points are plotted in Figure 4-9. Again, as in the preceding case, it is apparent that without the data point representing equipment 03, the results would be radically different.

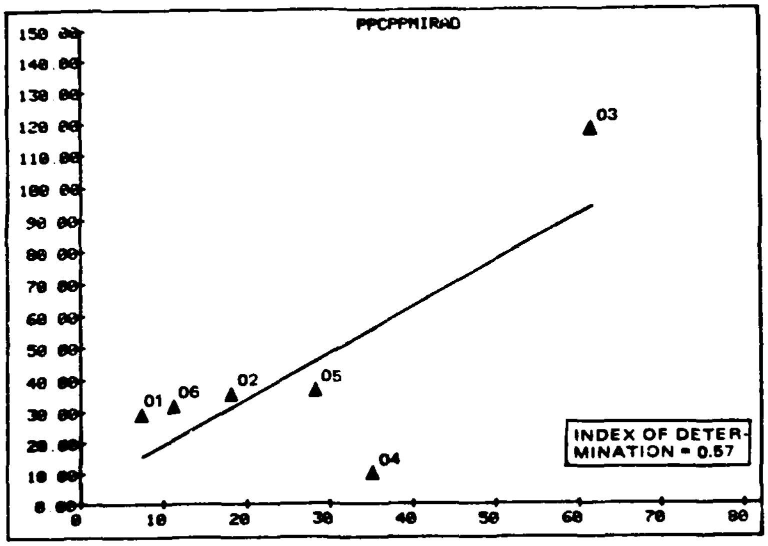

Figure 4-9. Predicted versus measured nonoperating failure rates (MIRADCOM method).

4.4.6 Measured Operating Failure Rate versus Total Number of Electronic Parts

The index of determination between the measured operating failure rate and the total number of electronic parts is 0.68.

The regression equation is:

$$Y = -55.4 + 1.22(X)$$

where

Y = observed operating failure rate

X = total number of electronic parts.

The regression equation is plotted in Figure 4-10

The measured operating failure rates appear to have a positive correlation with the total number of electronic parts. However, since the line is greatly dependent on Equipment 03, the determination of the magnitude of the slope would require further analysis using additional equipment points in the 3000 to 8000 parts region.

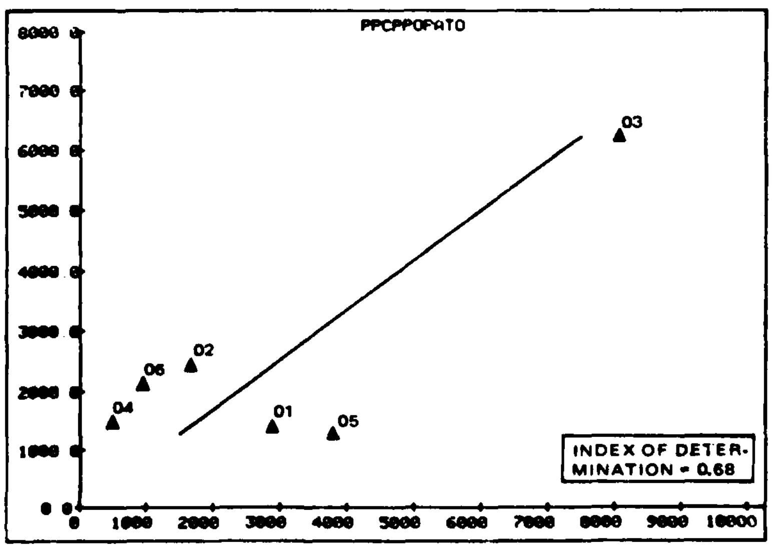

Figure 4-10. Measured operating failure rates versus total number of electronic parts.

4.4.7 Ratio of the Measured Operating Failure Rate to Nonoperating Failure Rate versus the Number of Microelectronic Parts

The index of determination is 0.12.

The regression equation is

$$Y = 131.8 - 0.044(X)$$

where:

Y = ratio of measured operating failure rate to nonoperating failure rate

X = the number of microelectronic parts.

The regression equation is plotted in Figure 4-11.

The ratios of measured operating to nonoperating failure rates appear to have a negative correlation with the number of microelectronic devices used in an item of equipment.

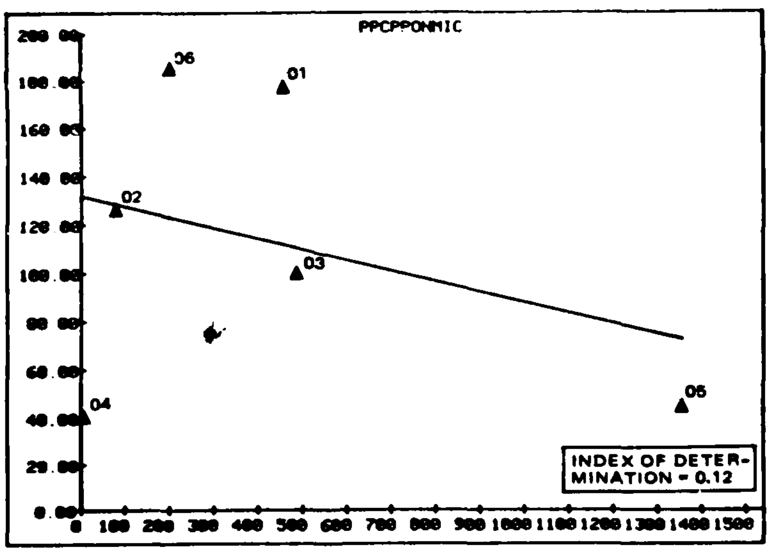

Figure 4-11. Ratio of measured operating failure rate to nonoperating failure rate versus number of micro electronic parts.

4.4.8 Ratio of Measured Operating to Nonoperating Failure Rate versus Percentage of Microelectronic Parts

The index of determination is 0.0005.

The regression equation is:

$$Y = 111.4 + 0.109(X)$$

where:

Y = the ratio of measured operating to nonoperating failure rate

X = the percentage of microelectronic parts

The regression equation is plotted in Figure 4-12.

The regression results did not confirm the commonly held belief that the ratio of operating to nonoperating failure rate decreases as the percentage of microelectronic parts is increased. On the contrary, the analysis results suggest that there is no significant relationship between the two factors.

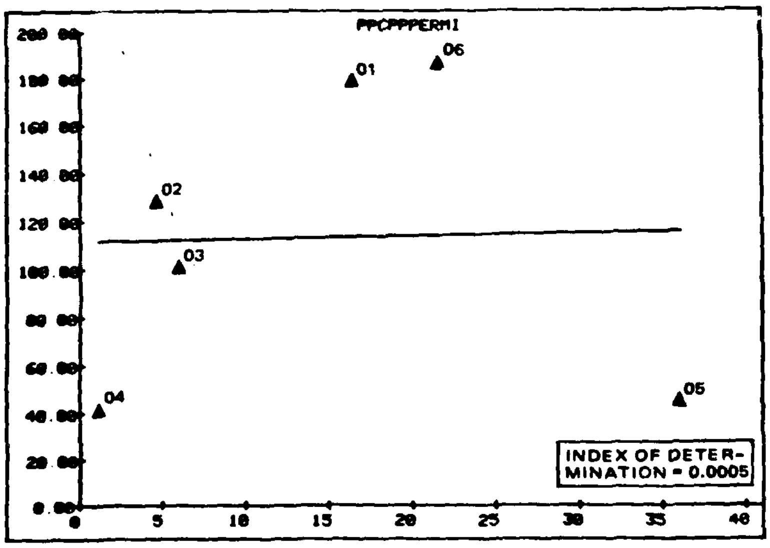

Figure 4-12. Ratio of measured operating to nonoperating failure rate versus percentage of microelectronic parts.

Other variables to consider are the inconsistencies in the criteria used for the determination of relative parts count and complexity factors, and/or the inclusion of special part failure rates for those parts not included in MIL-HDBK-217B. To examine this point in more detail, a summary of the contribution of non-217B parts was prepared for each of the six equipments studied. The impact of these parts was assessed in terms of the parts quantity and also the percentage of the total failure rate. The results are shown in Table 4-2.

4.4.9 Sources of Uncertainity and Bias

In each of the cases analyzed, it appears that further study, based on a larger sample of equipments having more uniformly distributed complexities may yield more meaningful results from which predictive models for nonoperating failure rates can be derived. However, it should also be recognized that the use of field maintenance data (from which failure or non-failure data are derived based on classification of maintenance action records) imposes limitations on the confidence that can be associated with the analysis results. The limitations arise because the data are influenced by the maintenance technician's choice of codes (How Malfunctioned and Action Taken) used for documenting the maintenance actions, by the accuracy and completeness of the data recorded (Job Control Number, Work Unit Code, etc.), and by the criteria used to classify the maintenance data records as either failures or other (non-failure) maintenance actions. Another factor that also is seen to have an influence on the data is the type of maintenance organization supporting the item (i.e.: RCM or POMO maintenance concept). In the latter case, a definite trend toward less emphasis on the documentation and more emphasis on aircraft sortie rate generation is evident in the data. Needless to say, these influences have nothing to do with hardware performance, but the data when analyzed by machine methods without regard to these factors gives the impression that the equipment reliability has degraded under the POMO maintenance organizational structure.

4.5 SELECTED ANALYSES

A correlation between some of the key data parameters was indicated in the regression analysis discussed in the preceding section. The analysis methods utilized and the rationale behind their use are discussed below before the specific analyses performed are presented. There are five items of interest:

1. Equipments that have sufficient data for statistical analysis
2. Equipment age effects
3. Environmental stress effects
4. Duty cycle method for failure rate derivation
5. Mission duration method for failure rate derivation.

These items are discussed below.

4.5.1 Sufficiency of Data

Equipments 01 and 02 have far more data than the other four equipments (03 through 06). In many cases, these two equipments were the only ones with sufficient data to permit a statistical analysis. Therefore, most of the selected analyses were concentrated on these two equipment types.

4.5.2 Effects of Age

Various scatter plots constructed without regard to individual equipment age, i.e., cumulative on-time, showed widely scattered points. It was suspected that the age of the individual equipments may have contributed to the scattering. Two experience curves of variation of failure rate are shown in Figure 4-13 as a function of equipment age. The curve from Hughes data reflects 30,000 equipment hours and 53 failures. The Honeywell curve was replotted from the paper entitled "The Effect of Endless Burn-in on Reliability" by Bezat and Montague (Reference 39). This curve reflects more than 300,000 equipment hours and over 800 failures. These curves are approximated by the following equation:

$$\lambda(t) = A\, t^{-\alpha} + \lambda_r$$

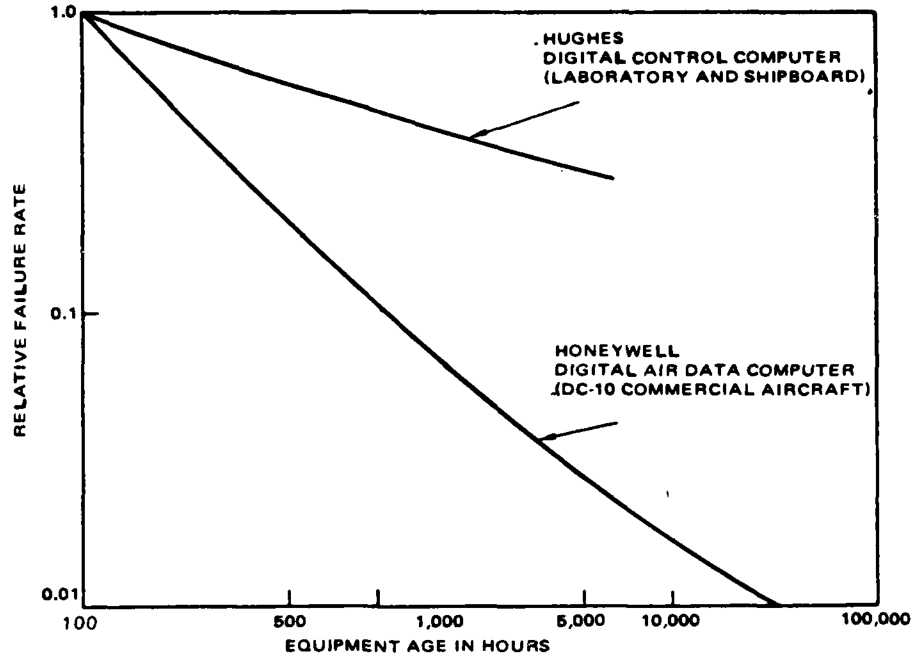

Figure 4-13. Relative failure rate versus equipment age.

where

$\lambda(t)$ = Failure rate as a function of time

A = Experience constant

t = Operating time

α = Experience growth factor

λ_r = Residue long-term failure rate.

For a first order approximation, the curves can be approximated as straight lines on a log-log paper, as shown in Figure 4-13. This means the equation becomes

$$\lambda(t) = A\,t^{-\alpha}$$

For this approximation, the respective α values are

α(Hughes Curve) = 0.29

α(Honeywell Curve) = 0.96

Using this concept, aging factors were developed for use as normalizing multipliers for the failure rates so that the failure rates for all of the equipments are compared at the same age point. The aging factor is expressed as

$$A.F. = \frac{\lambda_a}{\lambda_t} = \left(\frac{t}{t_a}\right)^{\alpha}$$

where

λ_a = Failure rate at normalization age point

λ_t = Measured failure rate at estimated age t

t_a = Normalization age

t = Estimated equipment age.

For the analyses the mean age of the equipments of interest was used as the normalizing age.

4.5.3 Flight Stress

Failure data representing equipment operated on different aircraft sometimes mask relationships that may exist unless the data are normalized to the equivalent environmental stress condition. An equipment subjected to higher stresses is expected to have more failures. The following screening expression from "Reliability Growth and Screening Concepts" (Reference 40) developed at Hughes (see Appendix C for the derivation of the screening expression) can be used to evaluate the severity of the environment.

$$f = D\,U\,(1 - e^{-kt})$$

where:

f = The number of failures accrued during time t.

D = Detection efficiency and is considered 1 for this study since a failure not detected is not a failure.

U = The number of flaws in the equipment at the start of the time interval.

k = The environmental severity factor.

t = The time interval studied.

The data representing the calendar year 1978 were used to develop the expression parameters. A computer program which minimizes the overall error by random point selection was employed to find U and k for equipments 01 and 02. The results are shown in Table 4-12. The kU products reflect the effect of the environment on the equipment failure rate. These products are utilized to normalize the failure data for use in pooling of data points from different aircraft platform environments (bombers versus fighters).

As an alternate approach to the development of an environmental stress factor, the ratios of the average failure rates for fighters versus bombers of each of the two equipment types were calculated and presented in Section 4.2.3. The resultant factors for the two methods were:

	Mean kU Ratio	Mean Failure Rate Ratio
Equipment 01 (TACAN)	1.46	1.27
Equipment 02 (UHF Radio)	1.60	1.51

The individual aircraft type failure rates within each broad category, i.e. fighter and bomber, as seen in Table 3-7 and the kU products from Table 4-12 showed variations of 10 to 40 percent from the averages for equipments 01 and 02. Therefore, the above ratios obtained via the two methods must be considered as inexact because of limitations imposed by the quality of the data from which they were derived. Subsequent analysis results indicated that the use of the environmental stress factor based on the mean failure rate ratio gave consistently better results as indicated by the correlation coefficients for the two data groups. Therefore, the analysis results presented in the following sections are based on the latter method of environmental stress factor derivation.

4.5.4 Duty Cycle Method

If the following relationship is assumed for failures expected as a function of operating and nonoperating failure rates, a regression analysis can be used to determine the failure rates from data of failures and times.

$$F = t_{OP}\,\lambda_{OP} + t_{NOP}\,\lambda_{NOP} \quad \text{with} \quad t_{TOT} = t_{OP} + t_{NOP} \tag{1}$$

TABLE 4-12. k AND U FACTORS FOR SELECTED AIRCRAFT AND EQUIPMENT APPLICATIONS

Aircraft Type	Equipment	k ($\times 10^{-6}$)	U	kU	Mean kU
Bomber Transport					
[illegible]	01	367	[illegible]	[illegible]	
L	01	405	3.2	[illegible]	[illegible]
O	01	245	4.0	[illegible]	
T	01	315	4.5	[illegible]	
Fighter Interceptor					
D	01	142	[illegible]	852	
M	01	231	[illegible]	1432	
R	01	511	[illegible]	2555	[illegible]
V	01	644	[illegible]	[illegible]	
Bomber Transport					
S	02	[illegible]	[illegible]	[illegible]	
I	02	[illegible]	[illegible]	[illegible]	[illegible]
O	02	[illegible]	[illegible]	[illegible]	
Fighter Interceptor					
D	02	[illegible]	[illegible]	[illegible]	
G	02	[illegible]	[illegible]	[illegible]	
M	02	[illegible]	[illegible]	[illegible]	[illegible]
F	02	[illegible]	[illegible]	[illegible]	
U	02	[illegible]	[illegible]	[illegible]	
X	02	[illegible]	[illegible]	[illegible]	

where:

F = Total number of failures experienced in the total time t_{TOT}

t_{OP} = Equipment operating time.

λ_{OP} = Equipment operating failure time.

t_{NOP} = Equipment nonoperating time in total time t_{TOT}.

λ_{NOP} = Equipment nonoperating failure rate.

Equation (1) can be written another way by letting

$$D = \text{duty cycle} = \frac{t_{OP}}{t_{TOT}}$$

$$F = t_{OP}\lambda_{OP} + t_{NOP}\lambda_{NOP} = t_{TOT}\left(\frac{t_{OP}}{t_{TOT}}\lambda_{OP} + \frac{t_{TOT} - t_{OP}}{t_{TOT}}\lambda_{NOP}\right)$$

$$= t_{TOT}\left[D\lambda_{OP} + (1 - D)\lambda_{NOP}\right]$$

Therefore

$$\frac{F}{t_{TOT}} = D\left(\lambda_{OP} - \lambda_{NOP}\right) + \lambda_{NOP} \qquad (2)$$

This relationship is shown in Figure 4-14.

Unfortunately, there are other failure inducing factors involved. Such factors include power on/off effects, environmental cycling effects and human induced conditions. If such failures are not affected by the operating or non-operating conditions then they would appear as an add-on term (noise) to Equation (2), i.e.,

$$\frac{F}{t_{TOT}} = D\left(\lambda_{OP} - \lambda_{NOP}\right) + \lambda_{NOP} + \lambda_{noise} \qquad (3)$$

This relationship is shown in Figure 4-15.

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NONOPERATING FAILURE RATES FOR AVIONICS STUDY.(U)
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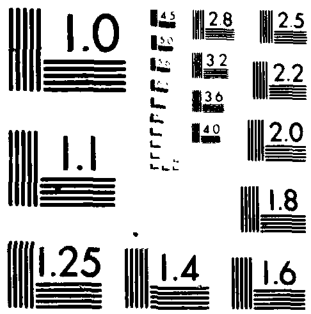

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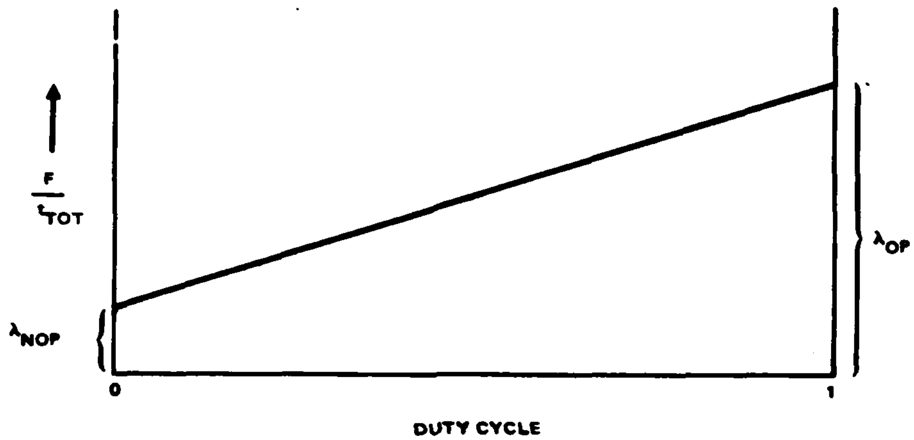

Figure 4-14. Ideal relationships between operating and nonoperating failure rates and duty cycle.

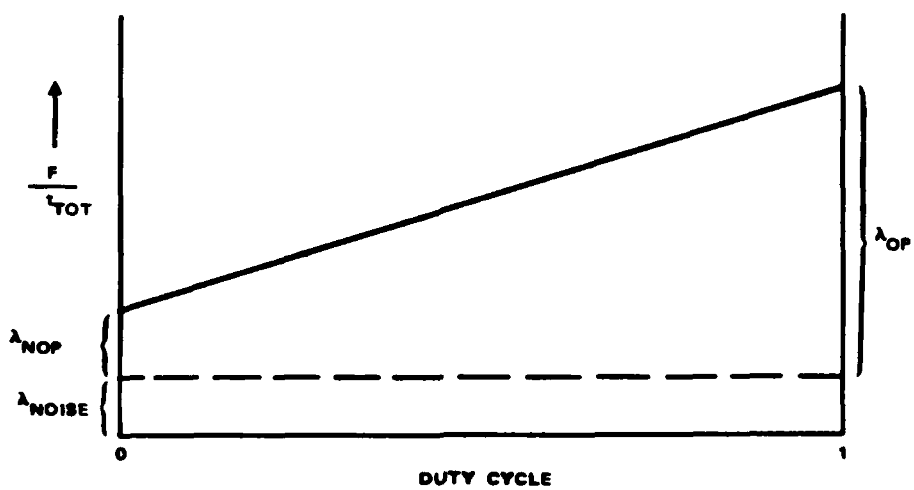

Figure 4-15. Relationships between operating, nonoperating, and noise failure rates and duty cycle.

It is unfortunate that at the present time λ noise cannot be segregated from λ_{NOP}. In any event, the intercept of the line on the left vertical axis will give a first approximation to the nonoperating failure rate, and the intercept on the right vertical axis indicates the operating failure rate.

4.5.5 Mission Duration Method

A paper by M. B. Shurman (Reference 41), indicated that the cumulative flight failure curve as a function of elapsed flight time takes the form of the curve shown in Figure 4-16. Following that concept, the total number of failures versus mission duration can be plotted to obtain a curve similar to the one shown in Figure 4-17. For this study this curve will be constructed using points of average numbers of failures per sortie per equipment and average mission durations for a number of aircraft types.

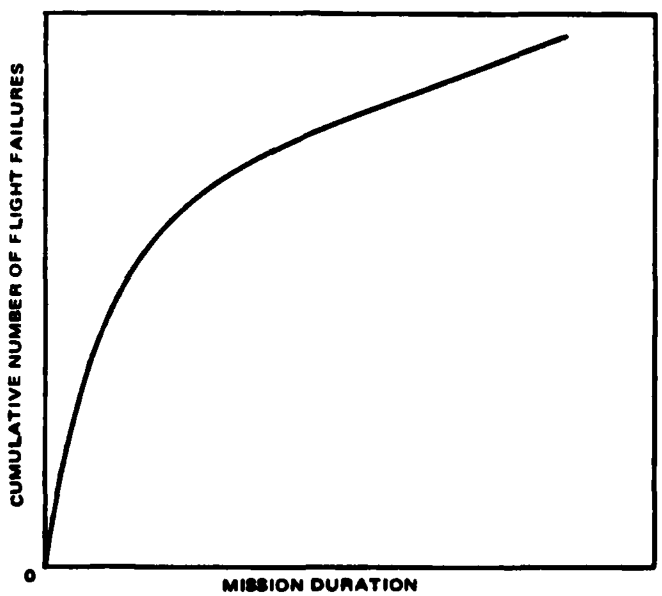

Figure 4-16. Cumulative flight failures vs. mission duration for jet aircraft equipment.

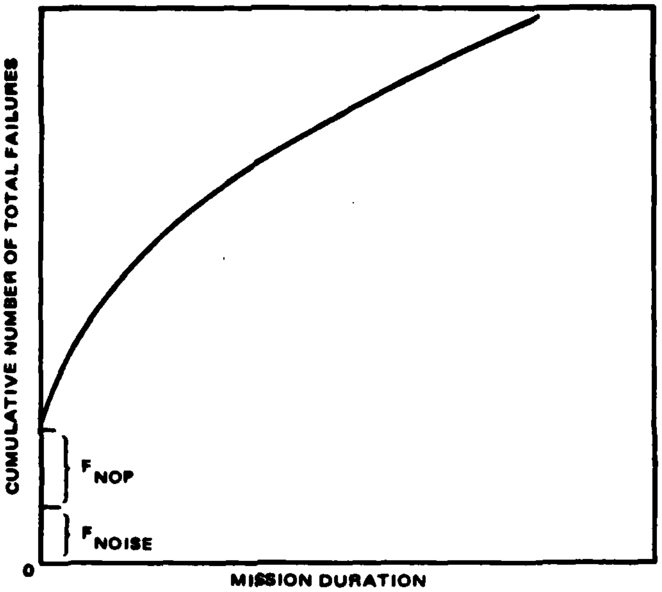

Figure 4-17. Cumulative total failures vs. mission duration for jet aircraft equipment.

In Figure 4-17 the curve intercept at the vertical axis gives the residual failures that are due to nonoperating stress and other causes. By dividing the failure figures by the appropriate cumulative time, a failure rate can be obtained. The slope of the right end of the curve will give the operating failure rate.

The Duty Cycle and Mission Duration analysis methods described were used in performing various analyses for estimating the failure rates of interest to the study. These analyses are individually discussed in the following sections, and plots of the data and equations established by means of the CURFIT regression analysis programs are also included.

4.5.6 Duty Cycle (Percent Operating Time) Regression Analysis

Data from equipments 01 and 02 were utilized in the duty cycle analyses. Both annual and monthly failures per equipment versus percent operating time plots were prepared. In each case, the scatter plots were such that several different curves and curve types could be drawn through them. However, when both the age factor and environmental stress factors were applied to all the data, the goodness of fit as measured by the index of determination (square of the coefficient of correlation) was improved to an acceptable value.

Because of differences in the apparent growth characteristics of the two equipment types, the age correction factors were derived using an iterative regression analysis approach that resulted in the best fit as indicated by the index of determination for each analysis. The values of α used for the calculation of the age correction factors were 0.35 and 0.20 for equipments 01 and 02 respectively. The resultant data matrix, indicating the age and environmental severity correction factors for each equipment application and the resultant effect on the parameter of interest, namely the equipment failure rate per 1000 sorties is given in Table 4-12.

The data sets pertaining to each of the two equipment types were analyzed using a least squares fit regression analysis program called CURVFIT.

The results of the CURVFIT analysis program indicate that a curve of the form Y = A + B(X) (straight line) is the best fit in both cases. The highest index of determination indicates that the best equations are as follows:

Equipment 01 (TACAN) F/EQ/YRC = 0.255 + ((0.102)(% OPTIME)) (4-1)

Equipment 02 (UHF Radio) F/EQ/YRC = 0.319 + ((0.229)(% OPTIME)) (4-2)

F/EQ/YRC = Failures per equipment per year corrected for age and environment

The regression equations and corresponding data points for the two data sets representing equipments 01 and 02 are plotted in Figures 4-18 and 4-19 respectively.

Using the equations from CURVFIT for straight lines, the nonoperating and operating failure rates can be calculated.

TABLE 4-12. AGE AND ENVIRONMENTAL STRESS FACTOR ANALYSIS TABLE

Aircraft Type*	Equip. Appl.	Equip Inv.	Env. Sev. Factor	Age Factor	Data for Mission Duration Analyses: Failures per 1000 Sorties			M. D. in hours	Data for Duty Cycle Analyses: Failures per equipment per year			Percent Operating Time
					W/O Correction	Corrected for Age	Corrected for Age & Env.		W/O Correction	Corrected for Age	Corrected for Age & Env.	
B	B9 01	336	1.27	1.07	13.65	14.63	18.52	7.74	0.68	0.73	0.92	5.18
	CL01	150	1.27	0.68	12.21	8.30	10.51	4.64	0.90	0.61	0.77	4.68
	CO01	477	1.27	1.09	3.12	3.40	4.31	2.51	0.66	0.72	0.91	7.19
	CT 01	308	1.27	0.90	4.96	4.48	5.67	3.41	1.52	1.37	1.73	14.14
F	TD01	691	1.00	1.19	1.35	1.60	1.60	1.22	0.39	0.46	0.46	4.70
	AM01	102	1.00	1.07	3.32	3.56	3.56	1.87	0.77	0.83	0.83	5.86
	AR01	262	1.00	0.88	4.92	4.35	4.35	1.63	0.86	0.76	0.76	3.83
	FV01	251	1.00	0.95	7.24	6.86	6.86	2.35	0.59	0.56	0.56	2.58
B	B8 02	288	1.51	0.86	21.65	18.67	28.13	7.74	1.09	0.94	1.42	5.23
	CL02	1236	1.51	0.96	13.14	12.63	19.03	4.64	0.99	0.95	1.43	4.69
	CO02	1008	1.51	1.06	5.82	6.19	9.33	2.51	1.24	1.32	1.99	7.22
[illegible]	TD02	497	1.00	0.91	5.75	5.21	5.21	1.22	1.65	1.49	1.49	4.70
	FG02	228	1.00	1.03	4.94	5.08	5.08	1.32	0.78	0.80	0.80	2.81
	AM02	102	1.00	0.96	9.79	9.42	9.42	1.87	2.28	2.20	2.20	5.86
	AR02	207	1.00	0.87	5.30	4.59	4.59	1.63	0.94	0.81	0.81	3.83
	TU 02	685	1.00	1.04	5.33	5.55	5.55	1.27	1.54	1.61	1.61	4.93
	TX 02	125	1.00	1.15	5.01	5.78	5.78	1.78	2.37	2.73	2.73	11.36

*Aircraft Type Legend: B = Bomber/Transport F = Fighter/Interceptor/Trainer

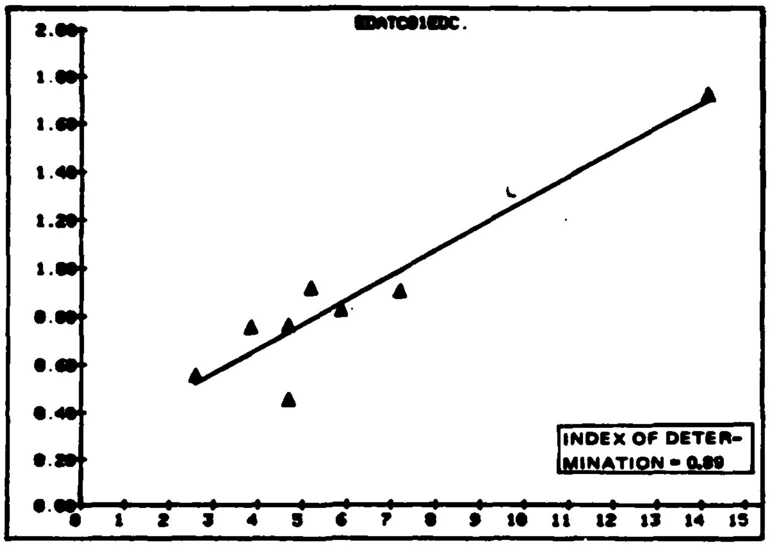

Figure 4-18, Failures per equipment per year versus percent optime corrected for age and environment – Equipment 01.

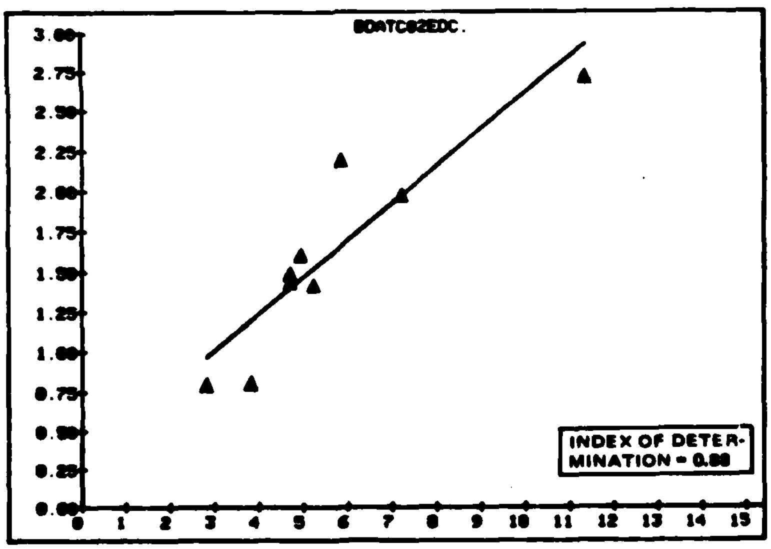

Figure 4-19. Failure per equipment per year versus percent optime corrected for age and environment – Equipment 02.

Dividing the first term of the equations relating to % OPTIME by the number of hours per year, and letting % OPTIME equal zero, yields the non-operating failure rate, λ_{NOP}. Thus, for equipment 01

$$\lambda_{NOP01} = \frac{(0.255)(10)^6}{8760} = 29.1 \text{ failures/million hours (F/mh)}$$

The subscripts 01 and 02 identify the respective equipments.

The operating failure rate is obtained from Equation (4-1) by setting % OPTIME to 100:

$$\lambda_{OP01} = 29.1 + \frac{(0.102)(10)^8}{8760} = 1193 \text{ F/mh}$$

The operating to nonoperating failure rate ratio is:

$$\frac{\lambda_{OP01}}{\lambda_{NOP01}} = \frac{1193}{29.1} = 41.0$$

Similar computations are repeated for equipment 02 using Equation (4-2)

$$F/EQ/YRC = 0.319 + ((0.229)\ (\%OPTIME))$$

and setting % OPTIME to zero, one obtains

$$F/EQ/YRC = 0.319$$

By repeating the previous steps for calculating the nonoperating failure rate, one obtains

$$\lambda_{NOP02} = \frac{(0.319)(10)^6}{8760} = 36.4 \text{ F/mh}$$

Dividing both terms of Equation (4-2) by 8760 and setting % OPTIME equal to 100, the operating failure rate is given by:

$$\lambda_{OP02} = 36.4 + \frac{(0.229)(10)^8}{8760} = 2651 \text{ F/mh}$$

The ratio is:

$$\frac{\lambda_{OP02}}{\lambda_{NOP02}} = \frac{2651}{36.4} = 72.8$$

4.5.7 Mission Duration Regression Analysis

The data set representing failures per 1000 sorties per equipment versus mission duration was analyzed for equipments 01 and 02 using the methods described in section 4.5.5. The CURVFIT analysis results and the regression equations and corresponding data points are shown in Figures 4-20 and 4-21, respectively based on the corresponding data from Table 4-12.

Selecting the equations having the highest index of determination yields the following failure rate expressions for equipments 01 and 02:

$$F/KESC = 0.187 + ((1.801)(MD)) \text{ (Table 4-8, EQ01)} \qquad (4\text{-}3)$$

$$F/KESC = 0.457 + ((3.670)(MD)) \text{ (Table 4-9, EQ02)} \qquad (4\text{-}4)$$

To obtain the failure rates and ratios based on failures per thousand sorties per equipment versus mission duration for equipment 01, using Equation (4-3) and setting mission duration (MD) equal to zero,

$$F/KESC = 0.187$$

The nonoperating failure rate is:

$$\lambda_{NOP01} = \frac{(F/KESC)\text{ (Average No. of Sorties per Year)}(10)^6}{(8760)\ (1000)}$$

$$= \frac{(0.187)\ (177)(10)^3}{8760} = 3.8 \text{ F/mh}$$

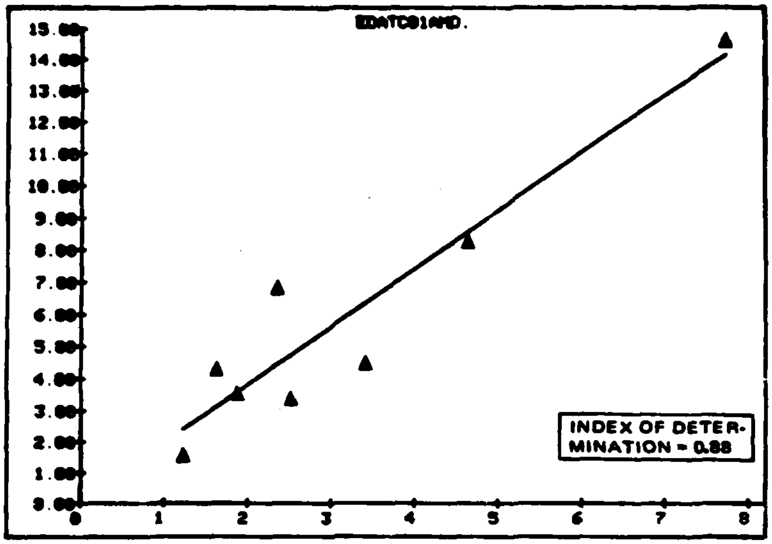

Figure 4-20. Failures per sortie versus mission duration corrected for age — Equipment 01.

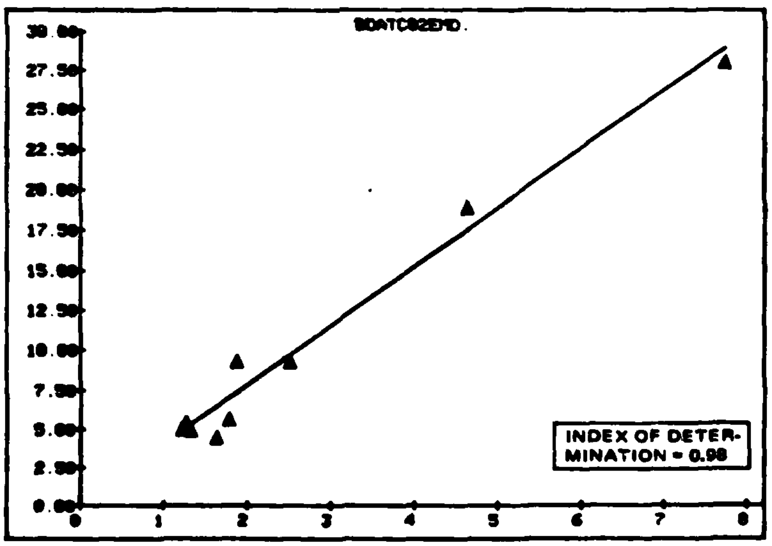

Figure 4-21. Failures per sortie versus mission duration corrected for age and environment — Equipment 02.

To calculate the operating failure rate for equipment 01, Equation (4-3) is converted to

$$F/KESC01 = \frac{(0.187) + (1.801)\ (MD)}{K}$$

in order to include operating failures occurring during both the mission time and ground operating time.

The slope of the line represented by this equation is the operating failure rate. Therefore

$$\lambda_{OP01} = \frac{1.801\ (10)^3}{K}$$

$$= 1385 \text{ F/mh for } K = 1.30$$

Taking the ratio of operating failure rate to nonoperating failure rate for equipment 01,

$$\frac{\lambda_{OP01}}{\lambda_{NOP01}} = \frac{1385}{3.8} = 364.5$$

To obtain the failure rates and ratios based on failures per thousand sorties per equipment versus mission duration for equipment 02, Equation (4-4) is used to obtain:

$$F/KESC02 = (0.457) + ((3.670)\ (MD))$$

and setting MD = 0

$$F/KESC02 = 0.457$$

The nonoperating failure rate is

$$\lambda_{NOP02} = \frac{(F/KESC02)\ (\text{Average No. of Sorties per Year})\ (10)^6}{8760\ (1000)}$$

$$= \frac{(0.457)\ (216)\ (10)^3}{8760} = 11.3 \text{ F/mh}$$

To calculate the operating failure rate, Equation (4-4) is converted to:

$$F/KESC02 = \frac{(0.457) + (3.670)\ (MD)}{K}$$

The slope of the line represented by this equation is the operating failure rate. Therefore

$$\lambda_{OP02} = \frac{3.670\ (10)^3}{1.30}$$

$$= 2823\ F/mh$$

Following the same procedures used for equipment 01

$$\frac{\lambda_{OP02}}{\lambda_{NOP02}} = \frac{2823}{11.3} = 249.8$$

The results of the preceding analyses for equipments 01 and 02 are summarized in Table 4-14. To provide a basis for comparison of the results obtained using the regression analysis method to those obtained using the When Discovered method of analysis, the average values of the measured failure rates for the censored data sets of equipments 01 and 02 are also included in Table 4-14.

In each of the cases analyzed, it appears that further study, based on a larger sample of equipments having more uniformly distributed complexities may yield more meaningful results from which predictive models for non-operating failure rates can be derived. However, it should also be recognized that the use of failure maintenance data (from which failure or non-failure data are derived based on classification of maintenance action records) imposes limitations on the confidence that can be associated with the analysis results. The limitations arise because the data are influenced by the maintenance technician's choice of codes used for documenting the maintenance actions, by the accuracy and completeness of the data recorded and by the criteria used to classify the maintenance data records as either failures or other (non-failure) maintenance actions.

TABLE 4-14. SUMMARY OF DC AND MD ANALYSIS RESULTS (AGE/ENV CORRECTION)

Failure Rates* and Ratios Based on Duty Cycle Analysis	Equipment 01	Equipment 02
λ_{OP}	1193	2651
λ_{NOP}	29.1	36.4
$\lambda_{OP}/\lambda_{NOP}$	41.0	72.8
Failure Rates* and Ratios Based on Mission Duration Analysis	**Equipment 01****	**Equipment 02**
λ_{OP}	1385	2823
λ_{NOP}	3.8	11.3
$\lambda_{OP}/\lambda_{NOP}$	364.5	249.8
Average Failure Rates* and Ratios Based on Measured Data	**Equipment 01**	**Equipment 02**
$\bar{\lambda}_{TOT}$	1545	2726
$\bar{\lambda}_{OP}$	1401	2417
$\bar{\lambda}_{NOP}$	7.4	18.3
$\bar{\lambda}_{OP}/\bar{\lambda}_{NOP}$	188.4	131.8

*Failure rates are in failures per million hours (F/mh)
**Analysis results based on age correction only

While i is true that some interesting relationships were developed using all three methods described in the preceding sections for the assessment of nonoperating failure characteristics of avionic equipment during this study, the inconsistent results reflect the influence of uncontrolled variables in the source data available for the analysis tasks.

A review of the maintenance data characteristics and a discussion of other factors which appear to influence the resultant data base is given in Section 4.6.

4.6 OBSERVATIONS REGARDING MAINTENANCE DATA CHARACTERISTICS

Although methods for assessing the reliability performance of airborne avionic equipments based on USAF field maintenance data were successfully developed and used on the previously completed OIR study (Reference 6), it has become evident during the work done on this study that the same data does not yield consistent results with which to characterize the nonoperating failure characteristics of avionic equipments.

Because of concern regarding these apparent inconsistencies, a careful review of other factors that might explain the differences was made. The conclusion reached following numerous discussions with the responsible logistics personnel at all levels (base, depot, and Command Headquarters) was that the differences stem from two different, but related, factors. The first factor relates to differences in the documentation of maintenance actions on the same equipment among the various commands and/or bases of interest to the study. The second factor relates to the functional characteristics of a given type of equipment.

Examples of differences in the documentation of maintenance actions are seen in the quality (incidence of incorrect, incomplete or missing records) of the data as well as the choice of codes used to document the When Discovered (WD) or How Malfunctioned entries on the maintenance records. Differences in documentation (and the resultant data) are also seen as a function of the type of maintenance organization supporting the item (i.e: RCM or POMO maintenance concept). In the latter case, a definite trend toward less emphasis on the documentation and more emphasis on aircraft sortie rate generation is evident in the data. Needless to say, these influences have nothing to do with hardware performance, but the data when analyzed by machine methods without regard to these factors gives the impression that the equipment reliability has degraded under the POMO maintenance organizational structure.

The equipment functional characteristics that are reflected in the data relate to the mission essentiality (is it a critical function, or a secondary convenience item) and failure detectability features of the equipment. For equipments that are primary mission essential, one would expect the user to be more critical of performance discrepancies, hence report malfunctions more frequently than if the item were of a lesser level of mission essentiality. Another of the equipments functional chracteristics relates to the exent to which performance discrepancies are detectable and the use conditions under which they are detectable. For example, for some types of equipment, discrepancies can be detected quite readily while the aircraft is on the ground, whereas for other types of equipment most discrepancies (including nonoperating failures would only be detected during flight. In the latter case, these failures would be classified as operating failures even though many of them may really have been nonoperating failures. This detectability characteristic is particularly true of the ARN-131 OMEGA low frequency navigation set, and to a lesser extent also true of the ARN-118 TACAN navigation set (Equipments 06 and 01 respectively). Both of these equipments therefore exhibit somewhat higher than expected operating to nonoperating failure rate ratios and correspondingly lower nonoperating failure rates.

When the differences in Air Force maintenance organizational structures (Reliability Centered Maintenance per AFM 66-1 versus Production Oriented Maintenance Organization per AFM 66-5) and maintenance practices implemented under the RCM or POMO organizations are also considered, it becomes quite apparent that still another variable (not in any way equipment performance related) can affect the data collected by the field maintenance data collection system.

It is believed that the combined effects of the differences in the equipment functional characteristics, the documentation of maintenance actions, and differences in maintenance organizational structures can cause significant differences in the data which in turn may lead to misleading analysis results if not properly recognized.

The analysis results and the major findings of the study are summarized in Section 5.0. The conclusions and recommendations resulting from the study follow in Section 6.0.

5.0 SUMMARY OF ANALYSIS RESULTS

The data on which this study was based are comprised of the field maintenance data for the calendar year ending 31 December 1978 for six different AN-designated avionic equipment types installed on 32 different equipment/aircraft applications among 17 different aircraft types. Collectively these data represent more than 3.8 million equipment flight hours, 8,255 equipments, and some 17,500 maintenance action record sets which document about 10,600 equipment failures.

The major results of the analysis are as follows. The calculated MTBF (using only failures detected during operating periods) was an average 23 percent higher for the six equipment types investigated than the Air Force reported MTBF (which included all failures). The MTBF difference was more than 50 percent for the C1108 video monitor. The MTBF improvement factors derived for each of the equipment types studied are presented in Figure 5-1. Comparable values were obtained using two other indirect methods for the ARN-118 TACAN and the ARC-164 UHF radio, as shown in Table 5-1. Comparing the operating to nonoperating failure rate ratios indicates that this characteristic varies over a wide range as shown in Figure 5-2. The average ratios of measured operating to nonoperating failure rates for the six equipment types investigated ranged between 41 and 188 and had an average value of 113. This method, however, possibly overestimates the ratio, because some failures that occur during nonoperating time are not detectable while the aircraft is on the ground; hence, they are counted as operating failures even though they may have occurred during nonoperating time. The ratios estimated for the ARN-118 TACAN and the ARC-164 UHF radio by means of the Duty Cycle analysis method were found to be 41 and 73 respectively compared to 188 and 132 with the When Discovered (WD) method.

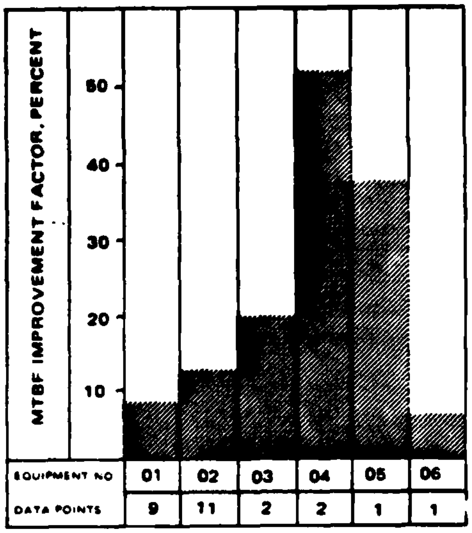

Figure 5-1. MTBF improvement factor.

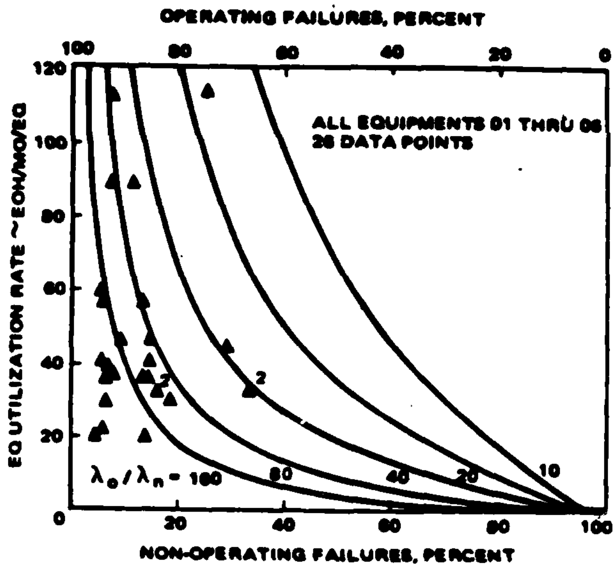

Figure 5-2. Ratio of operating to nonoperating failures.

TABLE 5-1. MTBF IMPROVEMENT OVER AIR FORCE REPORTED MTBF

Analysis Method	Based on Equipment	MTBF Improvement, %
WD (When Discovered) (By deleting failures discovered during non-operating period)	All 6 Equipments	22.7
	ARN-118 TACAN	8.6
	ARC-164 UHF Radio	12.3
DC (Duty Cycle) Regression Analysis	ARN-118 TACAN	29.5
	ARC-164 UHF Radio	2.8
MD (Mission Duration) Regression Analysis	ARN-118 TACAN	11.6
	ARC-164 UHF Radio	-3.4

The failure rates predicted and calculated from field data by means of several methods are summarized in Table 5-2. Only equipments 01 and 02 provided a sufficient number of data points for analysis using the Duty Cycle (DC) or the Mission Duration (MD) regression methods. The ratios of nonoperating to operating failure rates are also included in Table 5-3 to provide another index by which to compare the results.

TABLE 5-2. FAILURE RATE MATRIX (IN FAILURES PER MILLION HOURS)

Equipment Number	Predictions				Field Measured*					
	Operating	Nonoperating			Operating			Nonoperating		
	HDBK-217B	HDBK-217B 0 Stress	RADC Method	MIRADCOM Method	WD Method	DC Method	MD Method	WD Method	DC Method	MD Method
01	830	293.6	86.1	29.2	1401	1193	1385	7.4	29.1	3.8
02	289	131.2	61.8	35.7	2417	2651	2823	18.3	36.4	11.3
03	4237	741.3	589.7	118.8	6211	N/A	N/A	61.7	N/A	N/A
04	380	255.4	26.6	10.3	1445	N/A	N/A	35.3	N/A	N/A
05	366	106.3	101.0	37.3	1275	N/A	N/A	28.4	N/A	N/A
06	785	514.4	99.2	31.9	2102	N/A	N/A	11.3	N/A	N/A

*The three methods utilized to obtain field failure rates were:

(1) WD Method – Failures are categorized in accordance with When Discovered codes.

(2) DC Method – Failure rates are derived from Duty Cycle regression analyses.

(3) MD Method – Failure rates are derived from Mission Duration regression analyses.

TABLE 5-3. RATIOS OF OPERATING TO NONOPERATING FAILURE RATES

Equipment Number	Predicted			Field Measured*		
	HDBK 217B	217B RADC	217B MIRADCOM	WD Method	DC Method	MD Method
01	2.83	9.64	28.42	188.4	41.0	364.5
02	2.21	4.68	8.10	131.8	72.8	249.8
03	5.72	7.19	35.66	100.7	N/A	N/A
04	1.49	14.29	36.89	40.9	N/A	N/A
05	3.44	3.62	9.81	44.9	N/A	N/A
06	1.53	7.91	24.61	186.0	N/A	N/A

*See Table 5-1 for description of methods.

The failure rates obtained by means of the WD method; i.e., categorized according to the When Discovered Codes (WDC), are subject to variation in failure detectability and WDCs reported. The failure rates obtained by means of regression analysis are failure detectability and WDC free as the failure rates are established from curves rather than failure counts. This means that the classification of a failure as either operating or nonoperating is not contingent on the use of the WDC in documenting the maintenance action.

To place the failure rates in proper perspective it is necessary to relate the rates to the expected environmental conditions. Such a plot is shown in Figure 5-3. The failure rates for each equipment type are normalized in Figure 5-3 to the observed operating failure rate of that equipment. The operating failure rate point A, which has the value of one, serves as the starting point. This point is located at the environmental level A_u, a level that approximates the level the operating equipments experienced. The scale on the figure is used to mark the various environmental levels roughly in accordance with the π_E numerical values given in MIL-HDBK-217B.

The points in group B were obtained by dividing each observed nonoperating failure rate by its corresponding operating failure rate. The circled points were from the analyses based on the WDC. The triangles were from

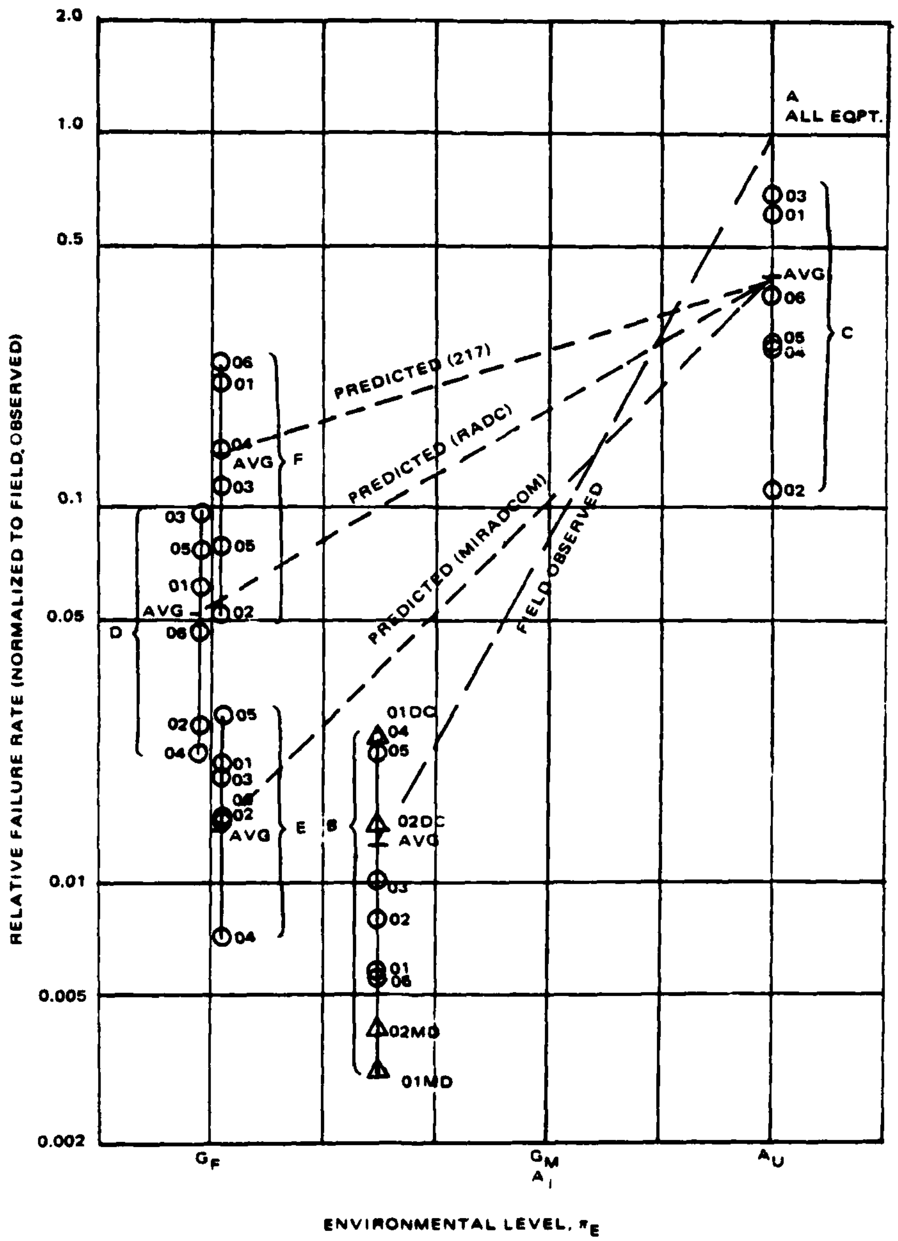

Figure 5-3. Graphical relationship of failure rates.

the MD and DC analyses. It is believed that the nonoperating environmental condition for the observed failure rates approximates a level somewhere between ground fixed (G_F) and ground mobile (G_M) environmental levles. The numbers associated with the data points signify the six equipment types investigated (01 through 06). The averages of the circled points are labeled AVG. The broken line connecting point A and the AVG point of group B shows roughly how the field observed failure rates vary from operating conditions to nonoperating conditions.

The points in groups C, D, E and F were obtained by dividing each predicted failure rate by the corresponding observed operating failure rate. All of the points were normalized to the observed operating failure rates from the analyses based on the WDC. Again, the numbers next to the points signify the equipment. The operating failure rate predictions for group C were based on MIL-HDBK-217B and manufacturers' estimates for parts not covered by the handbook. The nonoperating failure rate predictions for group D were based on RADC-TR-73-248 (Reference 34), on dormant failure rates. Those for group E were based on the nonoperating failure rates from LC-78-1, Missile Materiel Reliability Prediction Handbook (Reference 36). Those for group F were derived from MIL-HDBK-217B using zero stress, 30°C and ground fixed conditions, and manufacturers' estimates for parts not covered by the handbook. In general, environmental conditions for the nonoperating failure rate for the purpose of predictions are assumed to be close to the ground fixed (G_F) level.

Note that the observed nonoperating failure rates from the two analysis methods were lower than those predicted by both the RADC and MIRADCOM prediction methods used. Because a failure cannot be detected without energizing the equipment, it is very possible that the nonoperating failure rates from the two prediction documents contain some turn-on and test induced failures. However, considering the impact of failure detected at the time of initial turn-on, i.e.: unavailability of the system to perform its function, it is academic whether the failure occurred during turn-on or while the equipment was not energized (off).

Conclusions pertaining to critical analysis results are contained in the next section.

6.0 CONCLUSIONS AND RECOMMENDATIONS

As a result of this study, it has become clear that there are no simple means for assessing nonoperating failure rates, let alone defining what constitutes a nonoperating failure in a way that is acceptable to the majority of users. For this reason, it appears that perhaps a more pragmatic definition, based on consideration of the end user's needs would be most appropriate. For those interested in making relaibility predictions or assessments, nonoperating failure rate could encompass all failures that occurred during non-mission time. Similarly for an assessment of logistics resource impact, it is necessary to know what the failure rate of the equipment is when it is not operated or when it is in storage. Therefore, in this study, nonoperating failure rates were derived using several methods. The values and ratios of nonoperating and operating failure rates, and MTBF improvements are presented in the section on Summary of Analysis Results. The following gives overall conclusions and recommendations on specific precautions to be taken on future studies involving field data.

CONCLUSIONS

1. Nonoperating failures have a measurable effect on assessed operational MTBF of avionic equipment. For the equipments studied the average non-operating failure contribution is approximately 10 to 30 percent of the total number of failures for typical utilization rates of 20 to 60 hours per month. Therefore, it is imperative that only operating failures be counted in mission-oriented failure rate determination.
2. Field nonoperating failure rates cannot be predicted to a reasonable degree of accuracy using any of the established prediction methods. The data for the six equipment types investigated preclude the establishment of any consistent relationships between predicted and measured nonoperating failure rates.

3. The analysis results did not verify the current belief that microelectronic parts have a lower ratio of operating to non-operating failure rates than other types of parts. This finding, however, may be due to a number of other variables affecting the data on which this study was based.

4. Environmental severity factors (ESFs) appear to be both equipment and platform dependent. This indicates that the development of only average ESF or similar factors, such as π_E, for all types of avionic equipment may give very erroneous results with respect to a specific equipment type.

RECOMMENDATIONS

1. Any study of the effects of environmental stress on avionic equipment failure rates should also consider the influence of other factors such as equipment function and maintenance policy on the equipment's field failure rate.

2. Age has a significant influence on the magnitude of the failure rate at any point of time. Therefore, effects of age must be normalized in any failure rate studies that involve equipments having a variety of ages.

3. To permit more meaningful inferences to be drawn from the data base used for studies of this type, future studies should be planned to include equipments with the following characteristics:

   a. Relatively uniform and constant equipment/platfform combination population throughout the study period so that variation due to equipment age and flaw removal rates can be minimized.

   b. Each equipment type should be on several different aircraft types (more than four if possible) for each category (bomber, fighter, etc.) of interest in which the equipment is used.

   c. The equipment types selected should have a uniformly distributed range of complexity to prevent biasing of analysis results by equipment with extremely high or low complexities.

4. Differences in the maintenance action documentation procedures as implemented by the various operating commands and/or bases should be further investigated so that the influence of the documentation procedural differences can be accounted for in the performance assessment process by those using maintenance data collection system (MDCS) data for studies similar to the one reported on herein.

7.0 DEFINITIONS

AGEHRS	Age in Hours. The average equipment age at the end of the period of interest expressed in operating hours.
ALC	Air Logistics Center.
AT	Action Taken Code. The action taken code is used to identify the maintenance action that was taken, such as remove and replace. Action taken codes are standard for all equipment and are listed in all work unit code manuals. A complete list of authorized Action Taken codes is contained in AFM 300-4, Volume XI.
BIT	Built In Test. BIT includes all of the special circuitry and software designed into an avionic system to verify that the system is operative or, if the system is indicated to be not fully operative, to isolate the fault to an element of the system which can be removed and replaced to correct the condition.
CND	Cannot Duplicate. A reported discrepancy which cannot be duplicated (or verified) upon retest at either "0" level or "I" level of maintenance.
CONUS	Continental United States.
DCM	Deputy Commander for Maintenance. The commanding officer in charge of maintenance activities at the base level.
DORMANT	Dormancy is the state wherein a component or equipment is connected to a system in the normal operational configuration and experienced below normal and/or periodic operational stresses and environmental stresses, but is not energized or otherwise operated. The system may be in a dormant state for periods ranging from several hours to over 2,000 hours between operational missions for USAF aircraft. For the purposes of this study, dormancy is considered to be an element of the nonoperating condition.

EFHRS	Equipment Flight Hours. The number of equipment flight hours accumulated during a given time interval (EFHRS=FHRS(QPA)).
EOHRS	Equipment Operating Hours. The number of equipment operating hours accumulated during a given time interval (i.e., EOHRS = EFHRS(K)).
EUR	Equipment Utilization Rate, UR(K)
EQ	Equipment Number. The numeric equipment designator (01 through 06) assigned for convenience of notation when referring to the equipment in the data set.
FAILS (F)	Failure Occurences (F). The D056 computer definition of a failure occurrence related to a Work Unit Code is: "any Type 1 How Malfunctioned code reported in combination with an action taken indicating repair, adjustment or item replacement and one or more units produced". A Type 1 How Malfunctioned code indicates that the item no longer can meet the minimum specified performance requirement due to its own internal failure pattern.
FHRS	Flight Hours. The number of aircraft flight hours as reported in AFM 65-110 under active aircraft inventory flying time during a given time interval.
F/SRTIE	Failures per Sortie. The average annual failure rate expressed in terms of failures per sortie, i.e., $$\text{F/SRTIE} = \frac{\text{Total Failures}}{\text{Sorties}} = \frac{\text{FTOT x MD}}{\text{EFHRS}}$$
F/KSRTY	Failures per 1000 Sorties
FNOP	Nonoperating Failures
FOP	Operating Failures
FTOT	Total Failures
GT	Ground Operating Time. The operating time accumulated by a given item of equipment on the aircraft while the aircraft is operating on the ground under control of the flight crew during a typical mission.
HOW MAL	How Malfunctioned Code. The How Malfunctioned code is used to identify how the equipment malfunctioned, such as cracked. To provide maximum utility, these codes are also used to identify time compliance technical order status requirements, or to show that a maintenance action did not result from a defect. A complete list of authorized How Malfunctioned codes is contained in AFM 300-4, Volume XI. How Malfunctioned codes are listed in each work unit code manual for each individual type of equipment in both alphabetic and numeric order.

"I" LEVEL	Intermediate Level of Maintenance. For avionics systems, intermediate-level maintenance include all base-level maintenance performed at locations other than at the aircraft. It includes performing checks and corrective maintenance on LRUs and may include performing bit-and-piece repair on SRAs.
IM	Item Manager. The individual responsible for the management of an inventory item (such as an item of avionics equipment) at an ALC.
INV	Inventory. The number of aircraft systems in the active inventory as reported in 65-110 status report.
IROS	Increased Reliability of Operational Systems. The USAF Logistic Support Cost reporting system implemented by AFLC Regulation 400-16.
K	Use Factor. The ratio of equipment operating hours to equipment flight hours.
LAMNOP	Nonoperating Failure Rate, λ_{NOP}, $10^6 \div$ MTBFNON
LAMOP	Operating Failure Rate, λ_{OP}, $10^6 \div$ MTBFOP
LAMTOT	Total Failure Rate, λ_{TOT}
LOGISTIC CYCLE	The Logistic Cycle is the typical sequence of events that an item is exposed to during the performance of maintenance until it is again returned to its operational role. Typically, this cycle can have a duration of from several weeks to over one year.
LSC	Logistic Support Costs. Costs associated with supporting an item; includes costs of base labor, base material, costs to replace condemnations, transportation and shipping costs for non-base repairable items, technology repair center costs, and others when the cost is quantifiable and meaningful for effectiveness analysis.
LRU	Line Replaceable Unit. An LRU is an element of an avionic system ("black box") which can be removed and replaced by organizational-level maintenance personnel. LRU's which are faulty or suspect are removed from the aircraft and replaced with operative LRUs. The removed LRU is sent to an intermediate-level shop for maintenance.

MD	Mission Duration. The average weapon system mission duration, expressed in hours (derived from annual flight hours divided by annual sorties flown).
MDCS	Maintenance Data Collection System. The standard USAF maintenance data collection system (MDCS) defined in AFM 66-1.
MDS	Mission-Design-Series. The term MDS refers to the aircraft system designator (i.e., C-5A, F-4E, KC-135, etc.).
MI	Maintenance Index. The number of unscheduled maintenance manhours per equipment operating hour expended to support the equipment item. The time base can be equipment operating hours or equipment flight hours;

$$\text{Total Maintenance manhours} \div (QPA \times FHRS)$$

MMHRS	Maintenance Manhours. The number of unscheduled maintenance manhours expended in support of a given article as reported in the DO56 maintenance data summaries by WUC.
MTBFNOP	Nonoperating Mean Time Between Failures.
MTBFOP	Operating Mean Time Between Failures,

$$K \times QPA \times \frac{FHRS}{FOP}$$

MTBFTOT	Total Mean Time Between Failures,

$$K \times QPA \times \frac{FHRS}{FTOT}$$

MTBMA (EFH)	Mean Time Between Maintenance Actions (EFH). The value obtained by dividing the number of equipment flight hours by the number of maintenance actions as reported in the DO56 maintenance data summaries by WUC.
MTBMA (EOH)	Mean Time Between Maintenance Actions (EOH). The value obtained by dividing the number of equipment operating hours by the number of maintenance actions as reported in the DO56 maintenance data summaries by WUC.
NOPTIME	Nonoperating Time. The number of nonoperating hours accumulated by an item of equipment during both dormant and storage periods. See definitions of dormancy and storage also.

NRTS	Not Repairable This Station. Identifies an item of hardware which, for any of a variety of reasons (including policy, technical, and economic), is not designated to be repaired at the base level.
OPTIME	Operating Time. The number of operating hours accumulated by an item of equipment during both weapon system operations and operation during the performance of maintenance.
"O" LEVEL	Organizational Level of Maintenance. Maintenance performed by a using organization on its own equipment. For avionic equipment, organizational maintenance is performed at the aircraft.
OP/NOP	Ratio of operating failure rate to nonoperating failure rate.
P	Predicted MTBF (P). The predicted value of MTBF as reflected in the equipment manufacturer's final reliability prediction report.
P1	Predicted MTBF (P1). The reassessed value of the predicted MTBF based on the methods described in Section 3 of this report.
QPA	Quantity per Application. This is the quantity of identical installed items on a single unit of equipment that are reportable under the same WUC.
R	Required MTBF (R). The required value of equipment MTBF (θ_o) expressed in equipment operating hours as defined in the equipment procurement specification.
REMS	Removals. The number of maintenance actions coded as removed for the equipment as reported in the DO56 maintenance data summaries by WUC.
SM	System Manager. The individual responsible for the management of an operational weapon system at the ALC designated for the weapon system.
SORTIE (SRTY)	Sortie. A sortie begins at the initiation of the takeoff roll of the aircraft at the beginning of a flight, and ends 5 minutes after landing of the aircraft and/or engine shutdown following landing, whichever event occurs first.

STORAGE	Storage is defined as the state wherein an equipment is not connected to a system, but is in a supply storage status, with or without protective packaging, and during which time it experiences somewhat more benign environments than when in the dormant state.
SPO	System Program Office
TMAS	Total Maintenance Actions. The total number of maintenance actions reported against a given WUC as reported in the DO56 maintenance data summaries.
TMAXX	Total Maintenance Actions-Functional Subsystem. The total number of maintenance actions reported against the equipment functional subsystem as reported in the DO56 maintenance data summaries.
TOT/NOP	Ratio of total failure rate to nonoperating failure rate.
UR	Utilization Rate. The utilization rate, expressed in terms of flight hours per month per aircraft using the flight hours and inventory values reported in the 65-110 system operational status summaries.
WD	When Discovered. The When Discovered code is used to identify when a discrepancy requiring maintenance action was discovered, such as during a quality control inspection. When Discovered codes are listed in each work unit code manual for individual types of equipment.
WUC	Work Unit Code. The work unit code consists of five characters, and is used to identify the system, subsystem, and component on which maintenance is required or on which maintenance was accomplished. These codes are published in work unit code manuals for each weapon and support system. The first two positions of the work unit codes for aircraft identify functional systems, such as flight control system, antenna system, or launch control system. The third and fourth positions of the work unit code identify subsystem or major assembly. The fifth position of the work unit code normally identifies repairable items.
W/S	Weapon System. For the purposes of this report, this term is considered to refer to a formally designated operational aircraft system, regardless of whether the aircraft is a fighter, interceptor, bomber, transport, trainer, or other mission type.

%ABO — % Aborts. The percentage of all DO56 reported unscheduled maintenance actions on which the equipment item malfunction was reported as associated with a mission abort.

%ADJ — % Adjustments. The percentage of all DO56 reported unscheduled maintenance actions on which the equipment item maintenance action taken was reported as "Adjustment".

%COND — % Condemnations. The percentage of all DO56 reported unscheduled maintenace actions on which the equipment item maintenance action taken was reported as "Condemned".

%FAIL — % Failed. The percentage of all DO56 reported unscheduled maintenance actions which are classified as "Failures" in the DO56 reports summarizing AFM 66-1 MDC data analysis results.

%NOP — % Nonoperating Failure. The ratio of nonoperating to total failures expressed as a percentage.

%OPTIME — Percent Operating Time. The ratio of operating time to total calendar time expressed as a percentage.

%NRTS — % Not Repairable This Station. The percentage of all DO56 reported unscheduled maintenance actions on which the equipment item is reported as Not Repairable This Station (NRTS) and must be sent to a Depot or Special Repair Activity (SRA) for repair.

%REMS — % Removals. The percentage of all DO56 reported unscheduled maintenance actions on which the equipment item is reported as "Removed" from the aircraft and must be sent to the base avionics maintenance shop for subsequent maintenance action or to a Depot or Special Repair Activity (SRA) for repair.

%SHOP — % Shop Repairs. The percentage of all DO56 reported unscheduled maintenance actions on which the equipment item is reported as repaired at the base avionics maintenance shop.

%799 — % No Defect. The percentage of all DO56 reported unscheduled maintenance actions on which the equipment item is reported to have "No Defect" at the weapon system (On-Equipment) level.

%800 — % Removed to Facilitate Other Maintenance (RTFOM). The percentage of all DO56 reported unscheduled maintenance actions on which the equipment item is reported as "Removed to facilitate Other Maintenance" or removed for reasons other than failure or discrepancy on the part of the equipment item (How Mal codes 800-805 inclusive).

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APPENDIX A

DATA SOURCES AND FACILITIES VISITED

AVIONICS EQUIPMENT MANUFACTURERS

CONRAC Electronics, Inc.
Duarte, CA

Collins Radio, Inc.
Cedar Rapids, MI

Hughes Aircraft Company
Culver City, CA

IBM Federal Systems Division
Owego, NY

Magnavox Corp.
Ft. Wayne, IN

Norden Electronics, Inc.
Melville, L.I., NY

WEAPON SYSTEM PRIME CONTRACTORS

The Boeing Company
Wichita, KA

General Dynamics FW Division
Ft. Worth, TX

LTV-Fairchild
Dallas, TX

Lockheed-Georgia Corp.
Marietta, GA

McDonnell-Douglas Aircraft
St. Louis, MO

Northrop Aircraft
Hawthorne, CA

USAF FACILITIES

Aeronautical Systems Division
AFSC
Wright-Patterson AFB, OH

AF Flight Dynamic Labs., AFSC
Wright-Patterson, AFB, OH

Headquarters, AFLC
Wright-Patterson, AFB, OH

Headquarters, ATC
Randolph AFB, TX

Headquarters, MAC
Scott AFB, IL

Headquarters, SAC
Offutt AFB, NB

Headquarters, TAC
Langley AFB, VA

Oklahoma City ALC
Tinker AFB, OK

Headquarters, AFSC
Andrews AFB, MD

Headquarters, USAF
Washington, DC

Headquarters, ADC
Colorado Springs, CO

Rome Air Development Center
Griffiss AFB, NY

Sacramento ALC
McClellan AFB, CA

San Antonio, ALC
Kelly AFB, TX

Warner-Robins ALC
Robins AFB, GA

USAF AIR BASES

Davis Monthan AFB, AZ

George AFB, CA

Griffiss AFB, NY

Holloman AFB, NM

Kelly AFB, TX

Luke AFB, AZ

March AFB, CA

Mather AFB, CA

Nellis AFB, NV

Norton AFB, CA

Pease AFB, NH

Plattsburg AFB, NY

Randolph AFB, TX

Robins AFB, GA

Tinker AFB, OK

Travis AFB, CA

Williams AFB, AZ

APPENDIX B

FIELD DATA ANALYSIS SUMMARIES

Sample analysis results for ARN-118 TACAN Set on T-38 Aircraft for 12 months period ending 31 December 1978.

NOFRA STUDY FIELD DATA ANALYSIS SUMMARY

WEAPON SYSTEM D OP CMND ATC DATA WINDOW - 12 MONTHS
FU NO 44 QPA=1 EM/FH=1.30 PERIOD ENDING - DEC78
FU FUNCTION NAVIGATION
FU IDENT WUC 71Z00 LRU 00 FU DESCR: TACAN SYS DATE PROCESSED 10/26/79

MONTH YR	#S INV	OP TIME FLT HRS	TOTAL FAILS	TOTAL MA	MTBF FU HRS	MTBMA FU HRS	3 MO FMTBF	3 MO FMTBMA	% FAILS	% SH REPS	% NRTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16694	2	45	10851.0	482.3	9245.2	352.5	4	0	0	0.01	0	0	8346.9
78NOV	711	19094	3	71	8274.2	349.6	9831.7	420.6	4	0	0	0.01	0	0	6364.8
78OCT	709	21105	3	55	9145.7	498.9	11795.0	425.6	5	0	0	0.01	0	0	7035.1
78SEP	701	20303	2	61	13196.9	432.7	7390.6	389.0	3	0	0	0.01	0	0	10151.5
78AUG	701	22103	2	78	14367.1	368.4	6518.6	380.0	3	0	0	0.01	0	0	11051.6
78JUL	697	20130	7	70	3738.4	373.8	5620.5	437.4	10	3	0	0.01	0	0	2875.7
78JUN	690	22953	4	75	7459.6	397.8	6199.2	513.5	5	0	0	0.01	1	0	5738.1
78MAY	684	21861	4	48	7105.0	592.1	5204.3	578.3	8	0	0	0.00	0	0	5465.4
78APR	683	21947	6	46	4755.2	620.2	4783.3	558.5	13	0	0	0.00	0	0	3657.8
78MAR	669	24247	7	59	4503.1	534.3	5158.8	432.5	12	0	0	0.01	1	0	3463.9
78FEB	668	16356	4	46	5315.7	462.2	4578.6	349.5	9	0	0	0.01	1	0	4089.0
78JAN	664	14953	3	62	6479.5	313.5	4936.6	422.2	5	0	0	0.01	0	0	4984.2
TOTAL	691	241747	47	716	6686.6	438.9			7	0	0	0.01	3	0	5143.5

NOFRA STUDY FIELD DATA ANALYSIS SUMMARY

WEAPON SYSTEM D OP CMND ATC DATA WINDOW - 12 MONTHS
FU NO 44 QPA=1 EM/FH=1.30 PERIOD ENDING - DEC78
EU FUNCTION NAVIGATION
FU IDENT WUC 71ZA0 LRU 11 EU DESCR: REC/XMTR DATE PROCESSED 10/26/79

MONTH YR	#S INV	OP TIME FLT HRS	TOTAL FAILS	TOTAL MA	MTBF FU HRS	MTBMA FU HRS	3 MO FMTBF	3 MO FMTBMA	% FAILS	% SH REPS	% NRTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16694	15	37	1446.8	586.5	2175.3	1056.6	41	0	38	0.01	0	0	1112.9
78NOV	711	19094	9	16	2758.1	1551.4	2913.1	1573.1	56	0	38	0.00	0	0	2121.6
78OCT	709	21105	10	17	2743.7	1613.9	3175.6	1618.9	59	6	53	0.00	1	0	2110.5
78SEP	701	20303	8	17	3294.2	1552.6	2709.9	1377.9	47	0	59	0.00	1	0	2537.9
78AUG	701	22103	8	17	3591.8	1690.3	2492.4	1145.2	47	0	35	0.00	0	0	2762.9
78JUL	697	20130	14	25	1869.2	1046.7	2010.2	993.3	56	0	48	0.00	0	0	1437.8
78JUN	690	22953	12	32	2486.5	932.4	2345.7	1098.6	38	0	51	0.00	0	0	1912.7
78MAY	684	21861	16	28	1776.2	1015.0	1862.4	972.2	57	4	50	0.00	4	0	1366.3
78APR	683	21947	9	19	3170.1	1501.6	2323.3	1084.2	47	5	68	0.00	1	0	2438.6
78MAR	669	24247	22	48	1432.8	716.4	1900.6	914.2	50	0	32	0.00	0	0	1102.2
78FEB	668	16356	4	12	5315.7	1771.9	2052.5	1082.2	33	0	17	0.00	1	0	4089.0
78JAN	664	14953	12	23	1619.4	845.1	1565.3	1019.7	52	0	48	0.00	2	0	1246.1
TOTAL	691	241747	139	287	2260.4	1045.0			48	1	42	0.00	10	0	1739.2

NORRA STUDY FIELD DATA ANALYSIS SUMMARY

WEAPON SYSTEM D   OP CMND ATC
EQ NO 04   UPA=1   EM/FH=1.30
EQ FUNCTION NAVIGATION
EQ IDENT WUC 712R0 LRU 12 EQ DESCR: D/A CONV

DATA WINDOW - 12 MONTHS
PERIOD ENDING - DEC78

DATE PROCESSED 10/26/79

MONTH YR	WS INV	OP TIME FLT HRS	TOTAL FAILS	TOTAL MA	MTBF EQ HRS	MTBMA EQ HRS	3 MO EMTBF	3 MO EMTBMA	% FAILS	% SM REPS	% NRTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16694	0	2		10851.0	24653.8	8217.9	0	0	0	0.00	0	0	
78NOV	711	19094	1	3	24822.5	8274.2	13108.9	6554.5	33	0	33	0.00	0	0	19094.3
78OCT	709	21105	2	4	13718.5	6859.3	8256.5	5160.3	50	0	25	0.00	0	0	10552.7
78SEP	701	20303	3	5	8798.0	5278.8	8129.7	3871.3	60	0	40	0.00	1	0	6767.7
78AUG	701	22103	5	7	5746.8	4104.9	6518.6	2924.7	71	0	14	0.00	0	0	4420.7
78JUL	697	20130	2	9	13084.3	2907.6	6494.4	2345.2	22	0	22	0.00	0	0	10064.9
78JUN	690	22953	6	14	4973.1	2131.3	6676.1	2410.4	43	0	36	0.00	0	0	3825.4
78MAY	684	21861	5	13	5684.0	2186.1	6314.5	2457.6	38	23	23	0.00	2	0	4372.3
78APR	683	21907	2	9	14265.6	3170.1	9035.1	3348.2	22	0	44	0.00	1	0	10973.5
78MAR	669	24287	7	14	4503.1	2251.6	6018.6	3009.3	50	0	7	0.00	0	0	3463.9
78FEB	668	16356	0	1		21263.0	7440.2	3720.1	0	0	0	0.00	0	0	
78JAN	664	14953	5	9	3887.7	2159.8	7130.7	3565.3	56	0	67	0.00	0	0	2990.5
TOTAL	691	241787	38	90	8270.3	3491.9			42	3	29	0.00	4	0	6361.8

NORRA STUDY FIELD DATA ANALYSIS SUMMARY

WEAPON SYSTEM D   OP CMND ATC
EQ NO 04   UPA=1   EM/FH=1.30
EQ FUNCTION NAVIGATION
EQ IDENT WUC 712C0 LRU 13 EQ DESCR: MOUNT

DATA WINDOW - 12 MONTHS
PERIOD ENDING - DEC78

DATE PROCESSED 10/26/79

MONTH YR	WS INV	OP TIME FLT HRS	TOTAL FAILS	TOTAL MA	MTBF EQ HRS	MTBMA EQ HRS	3 MO EMTBF	3 MO EMTBMA	% FAILS	% SM REPS	% NRTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16694	2	8	10851.0	2712.7	14792.3	2958.5	25	0	0	0.00	0	0	8586.9
78NOV	711	19094	1	9	24822.5	2758.1	26217.8	3575.2	11	0	0	0.00	1	0	19094.3
78OCT	709	21105	2	8	13718.5	3429.6	41282.6	4856.8	25	0	13	0.00	0	0	10552.7
78SEP	701	20303	0	5		5278.8	81296.8	4782.2	0	0	0	0.00	2	0	
78AUG	701	22103	0	4		7183.6	28287.1	3259.3	0	0	0	0.00	0	0	
78JUL	697	20130	1	8	26168.6	3271.1	16885.0	2518.2	13	0	25	0.00	0	0	20129.7
78JUN	690	22953	2	14	14919.2	2131.3	17357.9	2650.0	14	0	21	0.00	0	0	11476.5
78MAY	684	21861	2	8	14209.9	3552.5	8847.3	2527.8	25	13	0	0.00	2	0	10930.7
78APR	683	21907	1	11	28531.2	2593.7	10168.5	2710.5	9	9	9	0.00	0	0	21907.1
78MAR	669	24287	7	16	4503.1	1970.1	9027.9	2579.4	44	6	13	0.00	0	0	3463.9
78FEB	668	16356	0	3		7087.7	59521.6	3306.8	0	0	0	0.00	0	0	
78JAN	664	14953	1	9	19438.4	2159.8	32088.0	3377.7	11	11	11	0.00	0	0	19452.6
TOTAL	691	241787	19	103	16580.6	3051.2			14	1	10	0.00	5	0	12723.5

NOFRA STUDY FIELD DATA ANALYSIS SUMMARY

WEAPON SYSTEM D   OP CMND ATC
FU NO 44   UPA=2   FH/FH=1.30
FU FUNCTION   NAVIGATION
FU IDENT WUC 712D0   LRU 14   FU DESCR: CONTROL

DATA WINDOW - 12 MONTHS
PERIOD ENDING - DEC78

DATE PROCESSED 10/26/79

MONTH YR	WS INV	OP TIME FLT HRS	TOTAL FAILS	TOTAL MA	MTBF FU HRS	MTBMA EQ HRS	3 MO FMTBF	3 MO EMTBMA	% FAILS	% SH REPS	% NRTS	MAINT INDEX	ANORIS	CONDS	MTBF FL HRS
78DEC	719	16694	8	36	5425.5	1205.7	10565.9	3081.7	22	17	3	0.00	0	0	4173.4
78NOV	711	19094	3	8	16548.3	12411.3	14300.6	8279.3	75	0	25	0.00	0	0	12729.5
78OCT	709	21105	3	8	18291.4	6859.3	11795.0	6351.2	38	38	25	0.00	1	0	14070.3
78SEP	701	20303	5	7	10557.6	7541.1	9033.0	6022.0	71	14	29	0.00	0	0	8121.2
78AUG	701	22103	6	11	9578.1	5224.4	9415.7	5135.9	55	36	27	0.00	0	0	8121.2
78JUL	697	20130	7	9	7476.8	5815.3	8887.0	5276.7	78	22	67	0.00	0	0	7367.8
78JUN	690	22953	5	13	11935.3	4590.5	10210.5	5260.0	38	8	23	0.00	0	0	5751.4
78MAY	684	21861	7	10	8120.0	5684.0	7077.8	4537.1	70	30	20	0.00	0	0	9181.0
78APR	683	21987	5	10	11412.5	5706.2	7070.9	4279.8	50	20	20	0.00	0	0	6286.1
78MAR	669	24287	13	19	4889.5	3318.1	6280.3	3903.9	68	52	47	0.00	0	0	8778.8
78FEB	668	16356	5	9	8505.2	4725.1	9157.2	4960.1	56	33	33	0.00	0	0	3730.4
78JAN	664	14953	5	9	7775.4	4319.6	11668.3	6417.6	56	67	78	0.00	0	0	6542.5
TOTAL	691	241747	72	145	8729.7	4334.8			50	26	28	0.00	1	0	6715.2

NOFRA STUDY FIELD DATA ANALYSIS SUMMARY

WEAPON SYSTEM D   OP CMND ATC
FU NO 44   UPA=1   FH/FH=1.30
FU FUNCTION   NAVIGATION
FU IDENT WUC 712XX   LRU 0X   EQ DESCR: TACAN S/S

DATA WINDOW - 12 MONTHS
PERIOD ENDING - DEC78

DATE PROCESSED 10/26/79

MONTH YR	WS INV	OP TIME FLT HRS	TOTAL FAILS	TOTAL MA	MTBF EQ HRS	MTBMA EQ HRS	3 MO FMTBF	3 MO EMTBMA	% FAILS	% SH REPS	% NRTS	MAINT INDEX	ANORIS	CONDS	MTBF FL HRS
78DEC	719	16694	37	138	586.5	157.3	778.5	268.3	27	8	11	0.02	0	0	451.2
78NOV	711	19094	25	111	992.9	223.6	914.6	245.8	23	0	7	0.01	2	0	763.8
78OCT	709	21105	33	106	831.4	258.8	917.4	247.9	31	4	12	0.01	2	0	639.6
78SEP	701	20303	28	103	932.6	256.3	813.0	228.0	27	1	14	0.01	4	0	725.1
78AUG	701	22103	29	124	990.8	231.7	749.9	200.8	23	3	8	0.01	0	0	762.2
78JUL	697	20130	43	136	608.6	192.4	664.8	201.5	32	3	16	0.02	1	0	468.1
78JUN	690	22953	41	162	727.8	184.2	768.0	226.0	25	1	13	0.02	1	0	559.8
78MAY	684	21861	43	121	660.9	234.9	618.7	222.1	36	7	16	0.01	9	0	508.4
78APR	683	21987	29	101	983.8	282.5	677.6	228.6	29	4	20	0.01	2	0	756.8
78MAR	669	28287	71	175	484.9	180.1	577.8	165.2	41	0	15	0.02	1	0	341.5
78FEB	668	16356	20	86	1063.1	247.2	738.8	202.5	23	3	6	0.01	2	0	817.8
78JAN	664	14953	34	129	571.7	150.7	729.3	222.1	26	5	19	0.02	2	0	439.8
TOTAL	691	241747	433	1492	725.2	210.6			29	3	13	0.01	26	0	558.3

NOFRA STUDY FIELD DATA ANALYSIS SUMMARY

WEAPON SYSTEM D   OP CMND ATC   DATA WINDOW = 12 MONTHS
FU NO 44   UPA=1   EH/FH=1.30   PERIOD ENDING - DEC78
FU FUNCTION NAVIGATION
FU IDENT WUC 71Z22 LRU 02 FU DESCR: TACAN FU   DATE PROCESSED 10/26/79

MONTH YR	WS INV	OP TIME FLT HRS	TOTAL FAILS	TOTAL MA	MTHF FU HRS	MTBMA FU HRS	4 MO FMTHF	4 MO FMTBMA	% FAILS	% SH REPS	% NRTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16694	25	83	86 .1	261.5	1320.7	486.6	30	7	18	0.01	0	0	667.8
78NOV	711	19094	14	32	1773.0	775.7	1673.5	763.6	44	0	25	0.00	1	0	1363.9
78OCT	709	21105	17	37	1613.9	741.5	1587.8	750.6	46	11	35	0.01	2	0	1241.5
78SEP	701	20303	16	34	1649.6	776.3	1377.9	655.6	47	3	41	0.01	4	0	1268.9
78AUG	701	22103	19	39	1512.3	736.8	1246.2	519.9	49	10	26	0.01	0	0	1163.3
78JUL	697	20130	24	51	1090.4	513.1	1068.7	461.3	47	4	43	0.01	0	0	838.7
78JUN	690	22953	25	73	1193.5	408.7	1205.4	379.5	34	1	29	0.01	0	0	918.1
78MAY	684	21861	30	59	947.3	461.7	921.6	440.2	51	14	32	0.01	8	0	728.7
78APR	683	21947	17	49	1678.3	582.3	1088.2	486.9	35	8	41	0.01	2	0	1291.0
78MAR	669	24247	49	93	643.3	338.9	891.6	424.9	53	8	28	0.01	0	0	494.8
78FEB	668	16356	9	25	2362.6	850.5	1167.1	526.7	36	12	20	0.00	1	0	1817.4
78JAN	664	14953	23	50	845.1	388.8	1018.7	534.8	46	14	50	0.01	2	0	650.1
TOTAL	691	241747	268	625	1172.7	502.8			43	8	32	0.01	20	0	902.0

W/S ENTRIES
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NOFRA STUDY FDAS--OPERATING FAILURES

WEAPON SYSTEM D OP CMND ATC DATA WINDOW - 12 MONTHS PAGE 1
FU NO 44 UPA=1 EH/FH=1.30 PERIOD ENDING - DEC78
EU FUNCTION NAVIGATION
FU IDENT WUC 71Z00 LRU 00 EU DESCR: TACAN SYS DATE PROCESSED 10/26/79

MONTH YR	#S INV	OP TIME FLT HRS	OPEN FAILS	TOTAL MA	MTBF EU HRS	MTBMA EQ HRS	3 MO EMTBF	3 MO EMTBMA	% FAILS	% SH REPS	% NRTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16694	2	45	10451.6	482.3	10565.9	432.5	4	0	0	0.01	0	0	8346.9
78NOV	711	19094	2	71	12411.3	349.6	15730.7	420.6	3	0	0	0.01	0	0	9547.1
78OCT	709	21105	3	55	9145.7	448.9	16513.0	425.6	5	0	0	0.01	0	0	7035.1
78SEP	701	20303	0	61		432.7	9033.0	389.0	0	0	0	0.01	0	0	
78AUG	701	22103	2	78	14367.1	368.4	6518.6	380.0	3	0	0	0.01	0	0	11051.6
78JUL	697	20130	7	70	3738.4	373.8	5628.5	437.4	10	3	0	0.01	0	0	2875.7
78JUN	690	22953	4	75	7459.6	397.8	6149.2	513.5	5	0	0	0.01	1	0	5738.1
78MAY	684	21861	4	48	7105.0	592.1	5529.5	578.3	8	0	0	0.00	0	0	5465.4
78APR	683	21947	6	46	4755.2	620.2	5062.2	538.5	13	0	0	0.00	0	0	3657.8
78MAR	669	24247	6	59	5254.6	538.3	5555.6	432.5	10	0	0	0.01	1	0	4041.2
78FEB	668	16356	4	46	5315.7	462.2	4960.1	349.5	9	0	0	0.01	1	0	4089.0
78JAN	664	14951	3	62	6479.5	313.5	5348.0	422.2	5	0	0	0.01	0	0	4984.2
TOTAL	691	241747	43	716	7308.6	438.9			6	0	0	0.01	3	0	5622.0

NOFRA STUDY FDAS--OPERATING FAILURES

WEAPON SYSTEM D OP CMND ATC DATA WINDOW - 12 MONTHS
FU NO 44 UPA=1 EH/FH=1.30 PERIOD ENDING - DEC78
FU FUNCTION NAVIGATION
EQ IDENT WUC 71ZA0 LRU 11 EU DESCR: REC/XMTR DATE PROCESSED 10/26/79

MONTH YR	#S INV	OP TIME FLT HRS	OPEN FAILS	TOTAL MA	MTBF EU HRS	MTBMA EQ HRS	3 MO EMTBF	3 MO EMTBMA	% FAILS	% SH REPS	% NRTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16694	14	37	1550.1	586.5	2281.3	1056.6	38	0	38	0.01	0	0	1192.4
78NOV	711	19094	9	16	2758.1	1551.4	2913.1	1573.1	56	0	38	0.00	0	0	2121.6
78OCT	709	21105	10	17	2743.7	1613.9	3440.2	1618.9	59	6	53	0.00	1	0	2110.5
78SEP	701	20303	8	17	3299.2	1552.6	3011.0	1377.9	47	0	59	0.00	1	0	2537.9
78AUG	701	22103	6	17	4789.0	1690.3	2733.6	1145.2	35	0	45	0.00	0	0	3683.9
78JUL	697	20130	13	25	2013.0	1046.7	2059.2	943.3	52	0	48	0.00	0	0	1548.4
78JUN	690	22453	12	42	2486.5	952.0	2305.7	1049.6	48	0	51	0.00	0	0	1912.7
78MAY	684	21861	16	28	1776.2	1015.0	1923.3	972.2	57	0	50	0.00	4	0	1366.3
78APR	683	21947	9	19	3170.1	1501.6	2391.6	1064.2	47	5	68	0.00	1	0	2430.6
78MAR	669	24247	21	44	1501.0	716.4	2124.2	914.2	48	0	32	0.00	[illegible]	0	1154.6
78FEB	668	16356	4	12	5315.7	1771.9	2340.9	1062.2	33	0	17	0.00	1	0	4089.0
78JAN	664	14953	4	23	2154.9	845.1	1749.5	1118.7	59	0	44	0.00	2	0	1661.4
TOTAL	691	241747	131	267	2399.0	1095.0			46	1	42	0.00	10	0	1845.4

KOERA STUDY FDAS--OPERATING FAILURES

WEAPON SYSTEM D   OP CMND ATC   DATA WINDOW = 12 MONTHS   PAGE 2
FU NO 44   UPA=1   EH/FH=1.30   PERIOD ENDING = DEC78
FU FUNCTION NAVIGATION
FU IDENT WUC 712B0 LRU 12 FU DESCR: D/A CONV   DATE PROCESSED 10/26/79

MONTH YR	AS INV	OP TIME FLT HRS	OPER FAILS	TOTAL MA	MTBF FU HRS	MTBMA EQ HRS	3 MO FMTBF	3 MO EMTBMA	% FAILS	% SH RLPS	% NRTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16694	0	2		10851.0	28653.8	8217.9	0	0	0	0.00	0	0	
78NOV	711	19094	1	3	24822.5	8274.2	15730.7	6554.5	33	0	33	0.00	0	0	19094.3
78OCT	709	21105	2	4	13718.5	6859.3	9173.9	5160.3	50	0	25	0.00	0	0	10552.7
78SEP	701	20503	2	5	13196.9	5278.8	9033.0	3871.3	40	0	40	0.00	1	0	10151.5
78AUG	701	22103	5	7	5786.8	4104.9	6518.6	2824.7	71	0	14	0.00	0	0	4420.7
78JUL	697	20130	2	9	13084.3	2907.6	6894.0	2345.2	22	0	22	0.00	0	0	10060.9
78JUN	690	22953	6	14	4973.1	2131.3	6676.1	2410.8	43	0	36	0.00	0	0	3825.4
78MAY	684	21861	5	13	5684.0	2186.1	6319.5	2457.6	38	23	23	0.00	2	0	4372.3
78APR	683	21987	2	9	14265.6	3170.1	9035.1	3388.2	22	0	44	0.00	1	0	10973.5
78MAR	669	24247	7	14	4503.1	2251.6	6018.6	3009.3	50	0	7	0.00	0	0	3463.9
78FEB	668	16356	0	1		21263.0	7490.2	3720.1	0	0	0	0.00	0	0	
78JAN	664	14953	5	9	3887.7	2159.8	7130.7	3565.4	56	0	67	0.00	0	0	2990.5
TOTAL	691	241747	37	90	8493.8	3491.9			41	3	29	0.00	4	0	6533.7

KOERA STUDY FDAS--OPERATING FAILURES

WEAPON SYSTEM D   OP CMND ATC   DATA WINDOW = 12 MONTHS
FU NO 44   UPA=1   EH/FH=1.30   PERIOD ENDING = DEC78
FU FUNCTION NAVIGATION
FU IDENT WUC 712C0 LRU 13 FU DESCR: MOUNT   DATE PROCESSED 10/26/79

MONTH YR	AS INV	OP TIME FLT HRS	OPER FAILS	TOTAL MA	MTBF FU HRS	MTBMA EQ HRS	3 MO FMTBF	3 MO EMTBMA	% FAILS	% SH RLPS	% NRTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16694	1	8	21701.9	2712.7	28653.8	2958.5	13	0	0	0.00	0	0	16695.0
78NOV	711	19094	1	9	24822.5	2758.1	39326.7	3575.2	11	0	0	0.00	1	0	19090.3
78OCT	709	21105	1	8	27437.1	4829.6	82565.2	4956.8	13	0	13	0.00	0	0	21105.
78SEP	701	20503	0	5		5278.8	81296.8	4782.2	0	0	0	0.00	2	0	
78AUG	701	22103	0	4		7183.6	28287.1	3259.3	0	0	0	0.00	0	0	
78JUL	697	20130	1	8	26168.6	3271.1	16885.4	2818.2	13	0	25	0.00	0	0	20129.7
78JUN	690	22953	2	14	14919.2	2131.3	17357.9	2630.0	14	0	21	0.00	0	0	11476.5
78MAY	684	21861	2	8	14209.9	3552.5	8847.3	2527.8	25	13	0	0.00	2	0	10930.7
78APR	683	21987	1	11	28581.2	2593.7	10164.5	2710.5	9	9	9	0.00	0	0	21987.1
78MAR	669	24247	7	16	4503.1	1970.1	9027.9	2574.0	44	6	13	0.00	0		3463.9
78FEB	668	16356	0	3		7067.7	59521.6	3306.8	0	0	0	0.00	0	0	
78JAN	664	14953	1	9	19438.9	2159.8	32088.0	3377.7	11	11	11	0.00	0	0	14952.6
TOTAL	691	241747	17	103	18486.5	4051.2			17	6	10	0.00	5	0	14220.0

NORMA STUDY FDAS--OPERATING FAILURES

WEAPON SYSTEM D   OP CMND ATC   DATA WINDOW - 12 MONTHS   PAGE 3
FU NO 44   OPA=2   EH/FH=1.30   PERIOD ENDING - DEC78
EU FUNCTION   NAVIGATION
EU IDENT WUC 712DD   LRU 14   EU DESCR: CONTROL   DATE PROCESSED 10/26/79

MONTH YR	NS INV	OP TIME FLT HRS	OPER FAILS	TOTAL MA	MTBF FU HRS	MTBMA EQ HRS	3 MO FMTBF	3 MO FMTBMA	% FAILS	% SH REPS	% NRTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16694	6	36	7234.0	1205.7	16435.9	3081.7	17	17	3	0.00	0	0	5564.6
78NOV	711	19094	2	4	24822.5	12411.3	22472.4	8279.3	50	0	25	0.00	0	0	19094.3
78OCT	709	21105	1	8	54874.1	6859.3	16513.0	6351.2	13	38	25	0.00	1	0	42210.9
78SEP	701	20303	4	7	13196.9	7541.1	10839.6	6022.0	57	14	29	0.00	0	0	10151.5
78AUG	701	22103	5	11	11493.7	5224.4	11298.8	5135.8	45	36	27	0.00	0	0	8841.3
78JUL	697	20130	6	9	8722.9	5815.3	9932.6	5276.7	67	22	67	0.00	0	0	6709.9
78JUN	690	22953	4	13	14919.2	4590.5	10848.7	5260.0	31	8	23	0.00	0	0	11476.5
78MAY	684	21861	7	10	8120.0	5684.0	7372.7	4537.1	70	30	20	0.00	0	0	6246.1
78APR	683	21947	5	10	11412.5	5706.2	7392.3	4279.8	50	20	20	0.00	0	0	8778.8
78MAR	669	24247	12	19	5253.6	3318.1	6878.4	3903.9	63	32	47	0.00	0	0	4041.2
78FEB	668	16356	5	9	8505.2	4725.1	9920.3	4960.1	56	33	33	0.00	0	0	6542.5
78JAN	664	14953	4	9	9719.2	4319.6	14261.3	6417.6	44	67	78	0.00	0	0	7476.5
TOTAL	691	241747	61	145	10303.9	4334.8			42	26	28	0.00	1	0	7926.1

NORMA STUDY FDAS--OPERATING FAILURES

WEAPON SYSTEM D   OP CMND ATC   DATA WINDOW - 12 MONTHS
FD NO 44   UPA=1   EH/FH=1.30   PERIOD ENDING - DEC78
EU FUNCTION   NAVIGATION
EU IDENT WUC 712XX   LRU 0X   EQ DESCR: TACAN S/S   DATE PROCESSED 10/26/79

MONTH YR	NS INV	OP TIME FLT HRS	OPER FAILS	TOTAL MA	MTBF FU HRS	MTBMA EQ HRS	3 MO FMTBF	3 MO FMTBMA	% FAILS	% SH REPS	% NRTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16694	26	138	834.7	157.3	1120.6	208.3	19	4	11	0.02	0	0	642.1
78NOV	711	19094	19	111	1306.4	223.6	1333.1	245.8	17	0	7	0.01	2	0	1005.0
78OCT	709	21105	21	106	1306.5	258.8	1240.1	247.9	20	4	12	0.01	2	0	1005.0
78SEP	701	20303	19	103	1389.2	256.3	1042.3	224.0	18	1	14	0.01	4	0	1068.6
78AUG	701	22103	24	124	1197.4	231.7	901.5	200.8	19	3	8	0.01	0	0	921.0
78JUL	697	20130	35	136	747.7	192.4	774.6	201.5	26	3	16	0.02	1	0	575.1
78JUN	690	22953	35	162	852.5	184.2	876.7	226.0	22	1	13	0.02	1	0	655.8
78MAY	684	21861	39	121	720.7	238.9	747.3	222.9	32	7	16	0.01	4	0	560.5
78APR	683	21947	25	101	1141.2	282.5	856.0	224.6	25	4	20	0.01	2	0	877.9
78MAR	669	24247	56	175	562.9	180.1	765.3	185.2	32	4	15	0.02	1	0	433.0
78FEB	668	16356	14	86	1518.6	247.2	960.0	202.5	16	3	6	0.01	2	0	1168.3
78JAN	664	14953	24	129	809.9	150.7	819.1	222.1	19	5	19	0.02	2	0	623.0
TOTAL	691	241747	337	1492	932.6	210.6			23	3	13	0.01	26	0	717.3

NOFRA STUDY FDAS--OPERATING FAILURES

WEAPON SYSTEM D   OP CMND ATC
FU NO 44   UPA=1   EM/FM=1.30
EQ FUNCTION NAVIGATION
EQ IDENT WUC 71ZZZ LRU 02 EQ DESCR: TACAN FU

DATA WINDOW - 12 MONTHS
PERIOD ENDING - DEC78

DATE PROCESSED 10/26/79

MONTH YR	WS INV	OP TIME FLT HRS	OPER FAILS	TOTAL MA	MTBF FU HRS	MTBMA EQ HRS	1 MO FMTBF	1 MO EMTBMA	% FAILS	% SH REPS	% NRTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16694	21	83	1033.4	261.5	1540.9	486.6	25	7	18	0.01	0	0	794.9
78NOV	711	19098	13	32	1909.4	775.7	1918.4	763.6	41	0	25	0.00	1	0	1468.0
78OCT	709	21105	14	37	1959.8	741.5	1876.5	750.6	48	11	35	0.01	2	0	1507.5
78SEP	701	20303	14	38	1885.3	776.3	1563.4	655.6	41	3	41	0.01	4	0	1450.2
78AUG	701	22103	16	39	1795.9	736.8	1366.8	519.9	41	10	26	0.01	0	0	1381.5
78JUL	697	20130	22	51	1189.5	513.1	1110.9	461.3	43	4	43	0.01	0	0	915.0
78JUN	690	22953	24	73	1243.3	408.7	1222.4	479.5	33	1	29	0.01	0	0	956.4
78MAY	688	21861	30	59	947.3	481.7	941.2	440.2	51	14	32	0.01	8	0	728.7
78APR	683	21947	17	49	1678.3	582.3	1113.9	486.9	35	8	41	0.01	2	0	1291.0
78MAR	669	24247	47	93	670.7	338.9	963.0	429.9	51	8	28	0.01	0	0	515.9
78FEB	668	16356	9	25	2362.6	850.5	1293.9	526.7	36	12	20	0.00	1	0	1817.4
78JAN	664	14953	19	50	1023.1	388.8	1125.9	538.8	38	14	50	0.01	2	0	787.0
TOTAL	691	241747	246	625	1277.5	502.8			39	8	32	0.01	20	0	982.7

W/S ENTRIES
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NOFRA STUDY FDAS--NON-OPERATING FAILURES

WEAPON SYSTEM D   OP CMND ATC   DATA WINDOW - 12 MONTHS   PAGE 1
FU NO 44   QPA=1   EM/FH=1.30   PERIOD ENDING - DEC78
FU FUNCTION NAVIGATION
FU IDENT WUC 71200 LRU 00 EQ DESCR: TACAN SYS   DATE PROCESSED 10/26/79

MONTH YR	AS INV	OP TIME FLT HRS	NONOP FAILS	TOTAL MA	MTBF FU HRS	MTBMA EQ HRS	% MU FMTBF	% MU FMTBMA	% FAILS	% SH REPS	% NRTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16690	0	45		482.5	73961.5	432.5	0	0	0	0.01	0	0	
78NOV	711	19094	1	71	546.1	349.6	26217.8	420.6	1	0	0	0.01	0	0	19094.5
78OCT	709	21105	0	55		498.9	81282.6	425.6	0	0	0	0.01	0	0	
78SEP	701	20303	2	61	268.3	832.7	80648.8	389.0	3	0	0	0.01	0	0	10151.5
78AUG	701	22103	0	78		368.4		580.0	0	0	0	0.01	0	0	
78JUL	697	20130	0	70		373.8		437.4	0	3	0	0.01	0	0	
78JUN	690	22453	0	75		397.8		513.5	0	0	0	0.01	1	0	
78MAY	688	21861	0	48		592.1	88072.6	519.3	0	0	0	0.00	0	0	
78APR	683	21987	0	46		620.2	81315.8	538.5	0	0	0	0.00	0	0	
78MAR	669	24247	1	59	505.7	534.3	72223.1	432.5	2	0	0	0.01	1	0	24247.5
78FEB	660	16356	0	46		862.2	59521.6	399.5	0	0	0	0.01	1	0	
78JAN	664	19953	0	62		313.5	64175.9	422.2	0	0	0	0.01	0	0	
TOTAL	691	241747	4	716	1586.9	438.9			1	0	0	0.01	3	0	60436.7

NOFRA STUDY FDAS--NON-OPERATING FAILURES

WEAPON SYSTEM D   OP CMND ATC   DATA WINDOW - 12 MONTHS
FU NO 44   UPA=1   EM/FH=1.30   PERIOD ENDING - DEC78
FU FUNCTION NAVIGATION
FU IDENT WUC 71ZA0 LRU 11 EQ DESCR: REC/XMTR   DATE PROCESSED 10/26/79

MONTH YR	AS INV	OP TIME FLT HRS	NONOP FAILS	TOTAL MA	MTBF FU HRS	MTBMA EQ HRS	% MU FMTBF	% MU FMTBMA	% FAILS	% SH REPS	% NRTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16690	1	37	555.7	586.5	73961.5	1056.6	3	0	38	0.01	0	0	16693.0
78NOV	711	19094	0	16		1551.0		1574.1	0	0	38	0.00	0	0	
78OCT	709	21105	0	17		1613.9	81282.6	1518.9	0	6	53	0.00	1	0	
78SEP	701	20303	0	17		1552.6	27098.9	1377.9	0	0	59	0.00	1	0	
78AUG	701	22103	2	17	267.1	1690.3	28247.1	1145.2	12	0	55	0.00	0	0	11051.6
78JUL	697	20130	1	25	543.5	1046.7	80926.8	943.4	8	0	48	0.00	0	0	20129.7
78JUN	690	22453	0	32		952.8		1098.6	0	0	51	0.00	0	0	
78MAY	688	21861	0	28		1015.0	88072.6	972.2	0	0	50	0.00	4	0	
78APR	683	21987	0	19		1501.6	81315.8	1088.2	0	5	56	0.00	1	0	
78MAR	669	24247	1	49	505.7	716.9	16055.8	914.2	2	0	52	0.00	0	0	24247.5
78FEB	660	16356	0	12		1771.9	18880.9	1062.2	0	0	17	0.00	1	0	
78JAN	664	19953	3	23	171.3	845.1	16000.0	1018.7	13	0	48	0.00	2	0	8984.2
TOTAL	691	241747	8	287	743.0	1095.0			3	1	42	0.00	19	0	30218.3

NORMA STUDY FDAS--NON-OPERATING FAILURES

WEAPON SYSTEM D OP CMND ATC
EQ NO 44 UPA=1 EM/FM=1.30
EQ FUNCTION NAVIGATION
EQ IDENT WUC 712H0 LRU 12 EQ DESCR: D/A CONV

DATA WINDOW - 12 MONTHS
PERIOD ENDING - DEC78

DATE PROCESSED 10/26/79

MONTH YR	WS INV	OP TIME FLT HRS	NONOP FAILS	TOTAL MA	MTBF EQ HRS	MTBMA EQ HRS	3 MO FMTBF	3 MO EXTBMA	% FAILS	% SH REPS	% NMTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16694	0	2		10851.0		8217.9	0	0	0	0.00	0	0	
78NOV	711	19094	0	3		8270.2	78653.4	6550.5	0	0	53	0.00	0	0	
78OCT	709	21105	0	4		6859.3	82565.2	5160.3	0	0	25	0.00	0	0	
78SEP	701	20303	1	5	536.5	5278.8	81296.8	3971.3	20	0	40	0.00	1	0	20303.0
78AUG	701	22103	0	7		4100.9		2824.7	0	0	14	0.00	0	0	
78JUL	697	20130	0	9		2907.6		2345.2	0	0	22	0.00	0	0	
78JUN	690	22953	0	14		2131.3		2410.8	0	0	56	0.00	0	0	
78MAY	684	21861	0	13		2166.1		2457.6	0	23	23	0.00	2	0	
78APR	683	21987	0	9		3170.1		3388.2	0	0	44	0.00	1	0	
78MAR	669	20207	0	14		2251.6		3009.3	0	0	7	0.00	0	0	
78FEB	668	16356	0	1		21263.9		3720.1	0	0	0	0.00	0	0	
78JAN	664	14953	0	9		2159.8		3565.3	0	0	67	0.00	0	0	
TOTAL	691	241747	1	90	6587.4	3891.9			1	3	29	0.00	4	0	241747.0

NORMA STUDY FDAS--NON-OPERATING FAILURES

WEAPON SYSTEM D OP CMND ATC
EQ NO 44 UPA=1 EM/FM=1.50
EQ FUNCTION NAVIGATION
EQ IDENT WUC 712C0 LRU 13 EQ DESCR: MOUNT

DATA WINDOW - 12 MONTHS
PERIOD ENDING - DEC78

DATE PROCESSED 10/26/79

MONTH YR	WS INV	OP TIME FLT HRS	NONOP FAILS	TOTAL MA	MTBF EQ HRS	MTBMA EQ HRS	3 MO FMTBF	3 MO EXTBMA	% FAILS	% SH REPS	% NMTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16694	1	8	555.7	2712.7	36900.8	2158.5	13	0	0	0.00	0	0	16693.0
78NOV	711	19094	0	9		2758.1	78653.4	3575.2	0	0	0	0.00	1	0	
78OCT	709	21105	1	8	581.9	3829.6	82565.2	4856.8	13	0	13	0.00	0	0	21105.0
78SEP	701	20303	0	5		5278.9		4782.2	0	0	0	0.00	2	0	
78AUG	701	22103	0	8		7183.6		3259.3	0	0	0	0.00	0	0	
78JUL	697	20130	0	8		3271.1		2414.2	0	0	25	0.00	0	0	
78JUN	690	22953	0	14		2131.3		2630.0	0	0	21	0.00	0	0	
78MAY	684	21861	0	8		3552.5		2527.8	0	13	0	0.00	2	0	
78APR	683	21987	0	11		2593.7		2710.5	0	9	9	0.00	0	0	
78MAR	669	20207	0	16		1970.1		2570.8	0	6	13	0.00	0	0	
78FEB	668	16356	0	3		7087.7		3306.8	0	0	0	0.00	0	0	
78JAN	664	14953	0	9		2159.8		3477.7	0	11	11	0.00	0	0	
TOTAL	691	241747	2	103	4175.7	3051.2			2	4	10	0.00	5	0	120873.0

NOFRA STUDY FDAS--NON-OPERATING FAILURES

WEAPON SYSTEM D   OP CMND ATC   DATA WINDOW - 12 MONTHS   PAGE 3
EQ NO 44   UPA=2   EM/FH=1.30   PERIOD ENDING - DEC78
EQ FUNCTION NAVIGATION
EQ IDENT MNC 71200 LRU 14 EQ DESCR: CONTROL   DATE PROCESSED 10/26/79

MONTH YR	AS INV	OP TIME FLT HRS	NONOP FAILS	TOTAL MA	MTBF EQ HRS	MTBMA EQ HRS	% NO FMTBF	% NO EMTBMA	% FAILS	% SH REPS	% NRTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16694	2	36	555.7	1205.7	29584.6	3081.7	6	17	3	0.00	0	0	16693.0
78NOV	711	19094	1	4	1092.2	12411.3	39326.7	8279.3	25	0	25	0.00	0	0	38188.5
78OCT	709	21105	2	8	541.9	6859.3	41282.6	6351.2	25	38	25	0.00	1	0	21105.0
78SEP	701	20303	1	7	1073.6	7541.1	58147.9	6022.0	14	14	29	0.00	0	0	40606.0
78AUG	701	22103	1	11	1068.3	5224.0	56998.1	5135.8	9	36	27	0.00	0	0	44206.0
78JUL	697	20130	1	9	1067.0	5815.3	88026.8	5274.7	11	22	67	0.00	0	0	40259.5
78JUN	690	22953	1	13	1048.5	4590.5	*****	5260.0	8	8	23	0.00	0	0	45905.1
78MAY	688	21061	0	10		5684.0	*****	4537.1	0	30	20	0.00	0	0	
78APR	683	21947	0	10		5706.2	*****	4279.8	0	20	20	0.00	0	0	
78MAR	669	20247	1	19	1611.4	3318.1	72223.1	5903.9	5	32	47	0.00	0	0	48495.0
78FEB	668	16356	0	9		4725.1	*****	4960.1	0	33	33	0.00	0	0	
78JAN	664	14953	1	9	1027.5	4319.6	64175.9	6417.6	11	67	78	0.00	0	0	29905.3
TOTAL	691	241747	11	145	1154.1	4334.8			8	26	28	0.00	1	0	43953.9

NOFRA STUDY FDAS--NON-OPERATING FAILURES

WEAPON SYSTEM D   OP CMND ATC   DATA WINDOW - 12 MONTHS
EQ NO 44   UPA=1   EM/FH=1.30   PERIOD ENDING - DEC78
EQ FUNCTION NAVIGATION
EQ IDENT MNC 712XX LRU 0X EQ DESCR: TACAN S/S   DATE PROCESSED 10/26/79

MONTH YR	AS INV	OP TIME FLT HRS	NONOP FAILS	TOTAL MA	MTBF EQ HRS	MTBMA EQ HRS	% NO FMTBF	% NO EMTBMA	% FAILS	% SH REPS	% NRTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	719	16694	11	138	50.5	157.3	2550.4	208.3	8	4	11	0.02	0	0	1517.6
78NOV	711	19094	6	111	91.0	223.6	2913.1	245.8	5	0	7	0.01	2	0	3182.4
78OCT	709	21105	12	166	85.2	258.8	3175.6	247.9	11	4	12	0.01	2	0	1758.8
78SEP	701	20303	9	103	59.6	256.3	3645.3	224.0	9	1	14	0.01	4	0	2255.9
78AUG	701	22103	5	124	106.8	231.7	4860.1	200.8	4	3	8	0.01	0	0	4420.7
78JUL	697	20130	8	136	66.7	192.4	4640.4	201.5	6	5	16	0.02	1	0	2516.2
78JUN	690	22953	6	162	97.4	184.2	6199.2	226.0	4	1	13	0.02	1	0	3825.4
78MAY	688	21061	4	121	130.2	234.9	3866.6	222.9	3	7	16	0.01	9	0	5265.4
78APR	683	21947	4	101	130.0	262.5	5252.6	224.6	4	4	20	0.01	2	0	5486.0
78MAR	669	20247	15	175	33.7	180.1	2329.8	185.2	9	4	15	0.02	1	0	1616.5
78FEB	668	16356	6	86	85.9	247.2	3132.7	202.5	7	3	6	0.01	2	0	2726.0
78JAN	664	14953	10	129	51.4	150.7	4218.4	222.1	8	5	19	0.02	2	0	1495.3
TOTAL	691	241747	96	1492	66.1	210.6			6	3	13	0.01	26	0	2518.2

NORPA STUDY FDAS--NON-OPERATING FAILURES

WEAPON SYSTEM D   MP CMMD ATC
FU NO 44   UPA21   EN/FH=1.30
FU FUNCTION NAVIGATION
FU IDENT WUC 71222 LMU 02 FU DESCR: TACAN FU

DATA WINDOW - 12 MONTHS
PERIOD ENDING - DEC78

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DATE PROCESSED 10/26/79

MONTH YR	AC INV	OP TIME FLT HRS	NONOP FAILS	TOTAL MA	MTNF FU HRS	MTBMA LO HRS	% NO FMTBF	% NO EMTBMA	% FAILS	% SM REPS	% NNTS	MAINT INDEX	ABORTS	CONDS	MTBF FL HRS
78DEC	714	18698	0	83	158.9	261.5	9245.2	888.6	5	7	18	0.01	0	0	4173.4
78NOV	711	19098	1	32	588.1	775.7	13108.9	743.6	3	0	25	0.00	1	0	19094.3
78OCT	709	21185	8	37	180.6	781.5	10920.6	750.6	8	11	35	0.01	2	0	7035.1
78SEP	701	20383	2	58	268.3	776.3	11613.8	655.6	6	3	41	0.01	4	0	10151.5
78AUG	701	22103	3	39	170.1	736.9	14123.5	519.9	8	10	26	0.01	0	0	7367.8
78JUL	697	20138	2	51	286.8	513.1	28142.3	461.3	4	4	43	0.01	0	0	10064.9
78JUN	690	2295	1	73	574.2	408.7	86789.3	479.5	1	1	29	0.01	0	0	22952.6
78MAY	688	2186	0	59		481.7	44256.3	480.2	0	14	32	0.01	8	0	
78APR	683	21947	0	49		582.3	40657.9	486.9	0	8	41	0.01	2	0	
78MAR	669	20287	2	93	252.8	358.9	12037.2	429.9	2	8	28	0.01	0	0	12125.7
78FEB	668	16356	0	25		850.5	11908.3	526.7	0	12	20	0.00	1	0	
78JAN	654	14953	0	58	128.4	308.8	10696.0	558.8	8	14	50	0.01	2	0	3738.2
TOTAL	691	281747	22	625	288.5	502.4			4	8	32	0.01	20	0	10988.5

W/S FMTNTES
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APPENDIX C

ENVIRONMENTAL STRESS SEVERITY FACTOR CONSIDERATIONS

This appendix describes a theory developed at Hughes Aircraft Company pertaining to the precipitation of failures from flaws in a piece of equipment by means of application of environmental screening stresses. By doing so the reliability of a piece of equipment can be increased. This theory is also applicable to equipments under normal usage stress. Therefore, the severity rate of environmental screening, as it is called herein, is a measure of the severity of any environment — natural or artifical — on the equipment. By analyzing the failure data with respect to time, the severity factor for a particular use environment can be determined. The following are excerpts from Reference 45 expounding this theory.

UNDERLYING POSTULATES

Hughes reliability growth theory is based upon the following postulates.

1. Flaws are latent failures which are due to imperfections in design, workmanship or material. Flawed items form a separate population possessing a significantly shorter stress life than the typical long life of high reliability items.
2. A failure is the precipitation of a flaw into an observable anomaly of performance. All observable anomalies are not observed, hence unobserved failures must be taken into account.
3. A screen is the application of stress to precipitate failures at a convenient time.
4. The rate at which flaws are forced into failures by a screen is proportional to the number of flaws in the equipment being screened.
5. The number of flaws in an equipment will decrease as more equipments are manufactured and tested since normal quality control and reliability procedures will correct flaws resulting from assignable causes.

6. **A test analyze and fix (TAAF) procedure accelerates the design reliability growth processes and, as design improvements are incorporated, has the apparent effect of replacing the equipment in TAAF with one of a higher serial number.**

7. **After the early production period, when the majority of the gross design flaws have been eliminated, the number of flaws in the equipment can be reduced by forcing them into observed failures and making reasonable repairs.**

8. **Flaws eliminated by the learning process are theoretically non-recurrent while flaws removed by the screening process may exist in subsequent equipments.**

THE THREE DIMENSIONAL CONCEPT

Product improvement occurs as a result of two simultaneous processes. One process is referred to as production learning and is measured by production sequence or time usually coincident with product serial number. The second process is due to screening which is measured by screen time.

Figure C-1 shows the relationship of the two processes. The instantaneous unreliability of a product, λ, represented on the vertical axis, is a function of two independent variables, each representing a different interpretation of "time". The effect of learning is represented in the M, λ plane and the effect of screening is represented in the t, λ plane. Thus, $\lambda(M, t)$ depicts the instantaneous failure rate of the Mth production equipment at screen time t.

The fundamental mathematical model that combines the learning and screening concepts to produce the three dimensional figure can be expressed as

$$\boxed{\lambda(M, t) = K\, k\, U(1, t)\, M^{-\alpha}(1-\alpha), \quad M > 10}$$

where D represents failure detection efficiency, k is the screen severity rate, U(1, t) denotes the number of flaws contained in equipment serial number one at time t, M represents and equipment serial number and denotes the constant learning factor. Each of these factors must be carefully addressed in order to plan and control a reliability growth program. The following sections further describe and justify the factors.

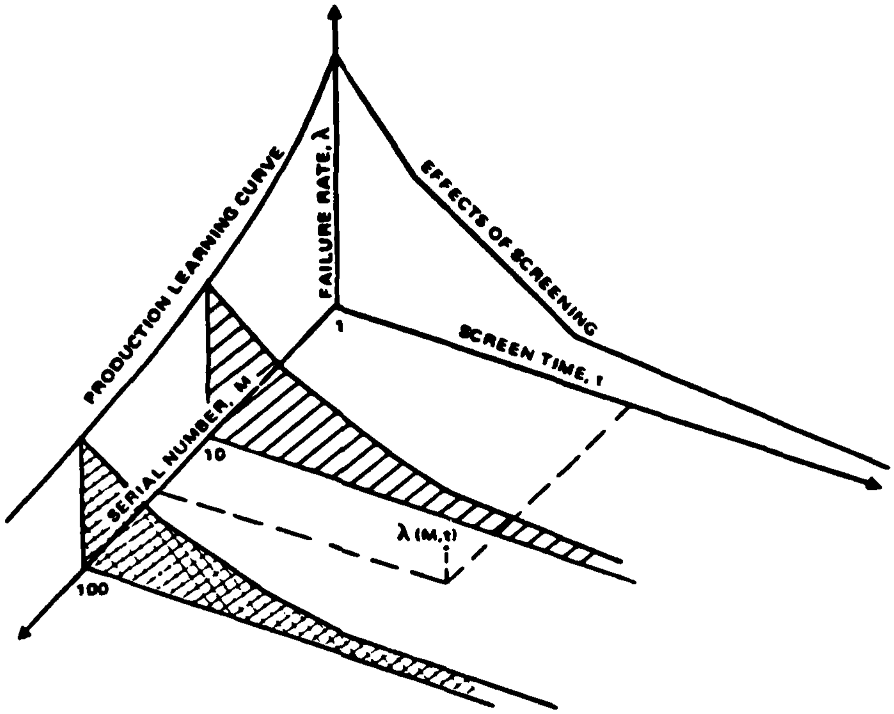

Figure C-1. Three dimensional concept of reliability growth.

THE LEARNING PROCESS

For many years estimates of the time to manufacture of product were calculated using the classical learning curve model [4]:

$$H_x = b\,x^{-k} \tag{1}$$

where H_x is the cumulative average time to produce the firxt x equipments, b denotes the time to produce the first equipment and k represents the learning curve slope. Furthermore, the time necessary to produce the xth equipment is defined by

$$h_x = b\,x^{-k}\,(1-k),\, x > 10 \tag{2}$$

On log, log graph paper expression (1) and expression (2) are represented by straight lines as shown in Figure C-2.

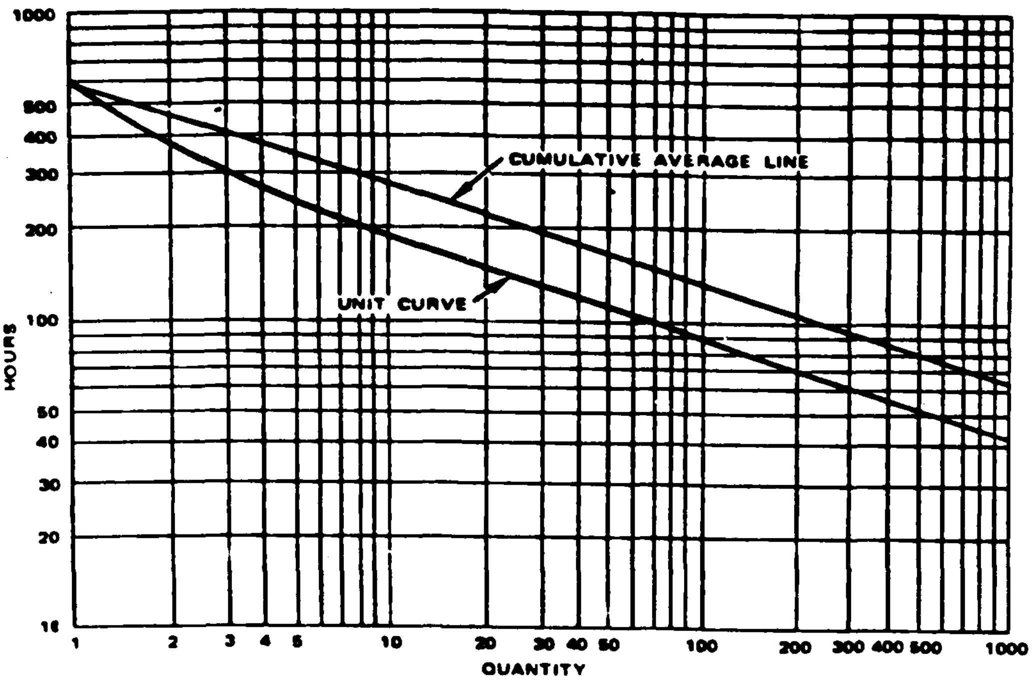

Figure C-2. Typical learning curve used in production time estimation.

Improvements in workmanship and processes and the implementation of design changes to correct problems are among the reasons for the reduction in time to produce successive equipments. Since these activities also remove flaws in the equipment, expression (1) can be rewritten in terms of failure rate to conform to the time designations previously discussed. Thus,

$$\bar{\lambda}(M,\ 0) = (1,\ 0)\ M^{-\alpha} \tag{3}$$

where $\bar{\lambda}(M, 0)$ is the cumulative average failure rate for equipments 1 through M at screen time 0; $\lambda(1, 0)$ denotes the failure rate for the first equipment and α is the learning curve slope.

Furthermore, the failure rate of an individual equipment at any screen time, t, can be written as

$$\lambda(M,\ t) = \lambda(1,\ t)\ M^{-\alpha}(1-\alpha),\ M > 10 \tag{4}$$

The latter relationship was verified for three Hughes production programs, each of which produced approximately 250 systems. Thus, we see that the classical learning process relationship expressed in terms of time to produce the xth equipment given by (2) properly holds when expressed in terms of failure rate of the Mth equipment at time t as given by (4).

THE SCREENING PROCESS

Three different screening models are employed by Hughes, namely, LOOK AHEAD, CREDIT and AFAR. The three models evolved from the same basic approach and differ only in the level of detail that may be attained and the method of calculating the strength of a screen.

The models are based on the postulate which states that the rate at which flaws are forced into failures by a screen is proportional to the number of flaws in the equipment being screened, i.e.,

$$\frac{\Delta U}{\Delta t} \propto U$$

where

U = number of flaws in an equipment

ΔU = the incremental change in U, and

Δt = the incremental time the equipment is exposed to an environment

Thus,

$$\frac{dU}{dt} = -kU$$

and by integration

$$[\log U]_o^t = [-kt]_o^t$$

$$U_t = U_o\, e^{-kt} \tag{5}$$

By definition, k is the severity rate of the environmental screen applied (this factor is discussed further in a subsequent section). U_t represents the number of flaws in the equipment at the end of screen time t and U_o represents the number of flaws in the equipment prior to the application of the screen.

The fundamental quantitative result of a screen or a test is the number of failures observed. In this case, the expected number of failures, f, that will be observed upon applying a particular screen is calculated by

$$f = D\,U_o\,(1 - e^{-kt}) \tag{6}$$

where D represents the detection efficiency. This result can be justified by recognizing that the number of <u>observable</u> failures for a particular screen is $U_o - U_t$ and the expected number of <u>observed</u> failures depends on the ability to detect the <u>observable</u> failures, thus

$$f = D\,(U_o - U_t).$$

Substituting expression (5) for U_t in the above yields expression (6).

From expression (6), $\lambda(t)$, the instantaneous failure rate at any time is defined as the derivative of observed failures with respect to time, i.e.,

$$\frac{df}{dt} = \lambda(t) = D\,k\,U_o e^{-kt} \tag{7}$$

and from (5)

$$\lambda(t) = D\,k\,U_t. \tag{8}$$

Furthermore, for the Mth equipment at screen time t,

$$\lambda(M,\ t) = D\,k\,U\,(M,\ t). \tag{9}$$

where $U\,(M,\ t)$ represents the number of flaws in the Mth equipment at the end of time t.

Figure C-3 generally illustrates the negative exponential effect of typical environmental screens on λ for a particular equipment serial number in the t, λ plane.

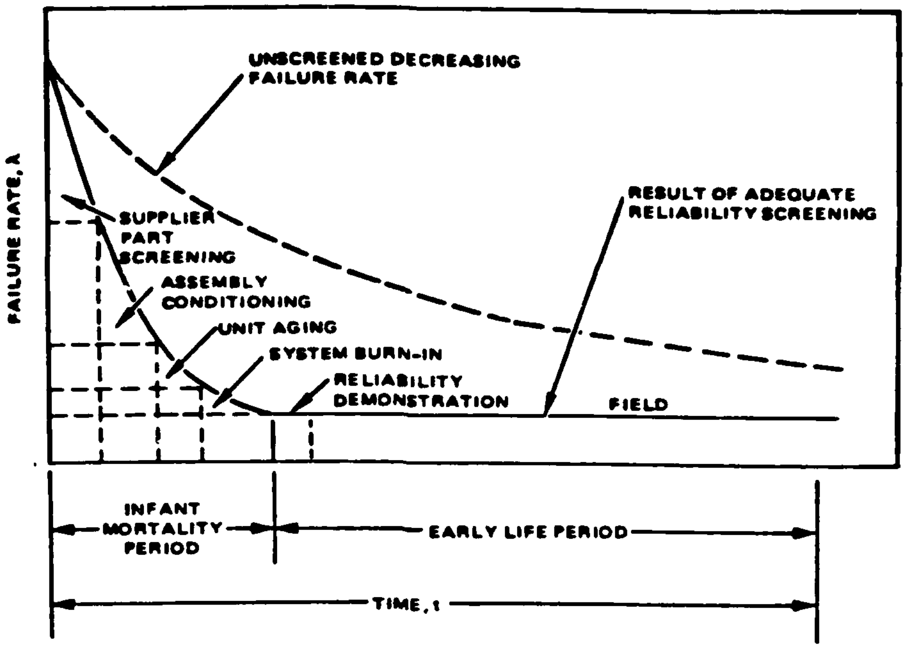

Figure C-3. Environmental screening effect on system reliability.

It follows from expression (9) that the failure rate of the first equipment at time t can be determined by

$$\lambda(1, t) = D\,k\,U(1, t)$$

and appropriate substitution of the above into the learning process relationship given by expression (4) yeilds the fundamental AFAR growth model

$$\boxed{\lambda(M, t) = D\,k\,U(1, t)\,M^{-\alpha}(1 - \alpha), \; M > 10.}$$

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